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New Equipment for Rearing Small Numbers of *Pseudosarcophaga affinis* (Fall.) (Diptera: Sarcophagidae) for Experimental Purposes

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Nutritional studies (House, 1954, a-d; House and Barlow, 1956) with the sarcophagid *Pseudosarcophaga affinis* (Fall.) have been in progress for a number of years at the Belleville laboratory. Recently a new technique was developed for the care of large numbers of small lots of *P. affinis*. This makes use of a convenient holder for larval rearing tubes; a cage assembly for rearing pupae and flies; and a rack to hold a large number of cages, each easily accessible and uniformly illuminated, in a minimum of space. When this equipment is used, the treatment of the insects is more uniform and less time-consuming than with the equipment previously used. The new technique and equipment are described in this paper.

Cabinet for Rearing Larvae

A method for rearing the larvae individually in small test tubes was described by House (1954a). As all the rearing at Belleville is done in a room with constant temperature and humidity, the test tubes are stored in a simple cabinet (Fig. 1). This is of thin plywood and is divided into compartments to hold 10 drawers. There are three ventilation holes in the back of each compartment. Each drawer is a tray with inside dimensions of about 11½ by 9¼ by 1½ inches. The sides and backs of the drawers are reduced in height, except near the corners, for ventilation. Each drawer is divided lengthwise by three wooden strips each of which has 20 equally spaced grooves. Each drawer can hold 60 test tubes resting in these grooves in a nearly horizontal position for easy inspection. The cabinet is enamelled white.

Pupa Container and Fly Cage

A removable container for pupae is attached to a cage, which receives the flies as they emerge. This container (Fig. 2) is made from a wooden block about 2½ by 2½ by 3½ inches, and holds about 50 pupae. It is essentially a wooden tube with two side arms, A and B. The bore of the tube increases in diameter in three steps, C, D, and E. The diameters of the bore at C, the side arms, and the hole in the front of the fly cage are so related that either of the side arms or the stopper closing C closes the hole in the front of the fly cage. The two larger bores of the tube, D and E, which are approximately equal in length, are separated by a disc of 16-mesh copper screening, F, held in place with a fillet of wood-filler. The mature larvae are put in E, which is about half-filled with fine, dry sawdust, to pupate. Cork stoppers are inserted into the end G and into the opening in side arm A, the container is inverted, and side arm B is inserted in a hole in the plastic front of the fly cage, a saw kerf, H, serving as a hook to hold the two units together. When pupation is completed, a stopper is inserted at C and the container is turned over and is gently shaken until the sawdust drops through the screen F, leaving the pupae above the screen.

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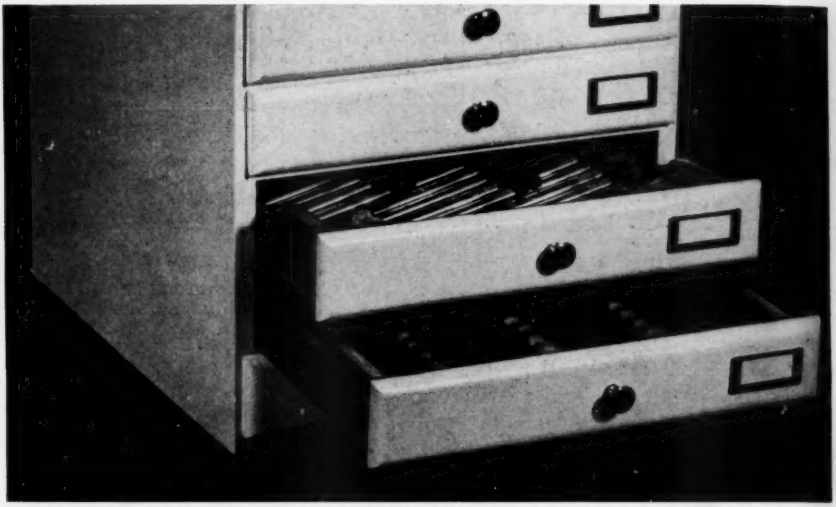


Fig. 1. Drawers of cabinet for rearing larvae.

The stopper at A is removed and stored in side arm B. The side arm A is then hooked into the opening in the front of the fly cage, and the emerging flies are free to pass through.

The fly cage (Fig. 2) is used to confine the flies from mating until death. This cage is approximately seven inches square and 5½ inches deep and has a removable clear plastic front, which slides upwards in grooves, and a plastic screen back. The plastic front has a hole in its center by which the pupa container is attached and through which the food can be replenished daily with a pipette. For *P. affinis*, which is viviparous, a removable clear plastic floor covering is placed over the cage bottom to aid in collecting newly deposited larvae. The fly cage is enamelled white and illuminated and the pupa container is painted flat black to absorb light, and the phototactic response is used to attract the flies into the cage. The flat paint on the pupa container provides a surface to which the newly emerged flies can easily cling until their wings are fully formed, and the smooth enamel makes the fly cage easy to clean. Painting the floor of the fly cage with black enamel makes the newly deposited larvae more readily visible.

Cage Rack

Fig. 3 shows the cage rack, which consists of two sections each of six shelves separated by a center section on which are mounted six fluorescent lights. The three sections form a rack resembling two bookcases placed back to back against an illuminated center section. The control panel and electrical services are on one end for easy access. The shelf sections are 52⅜ inches high, 54¼ inches long, and 9¾ inches wide. They are strengthened at each end with wooden facings on the front. These facings are widest at the service end. Each shelf is 5¾ inches wide and is backed and divided by narrow strips to hold six cages in alignment. The shelves are mounted on rollers that move on L-shaped aluminum supports so that the shelves can be drawn forward until

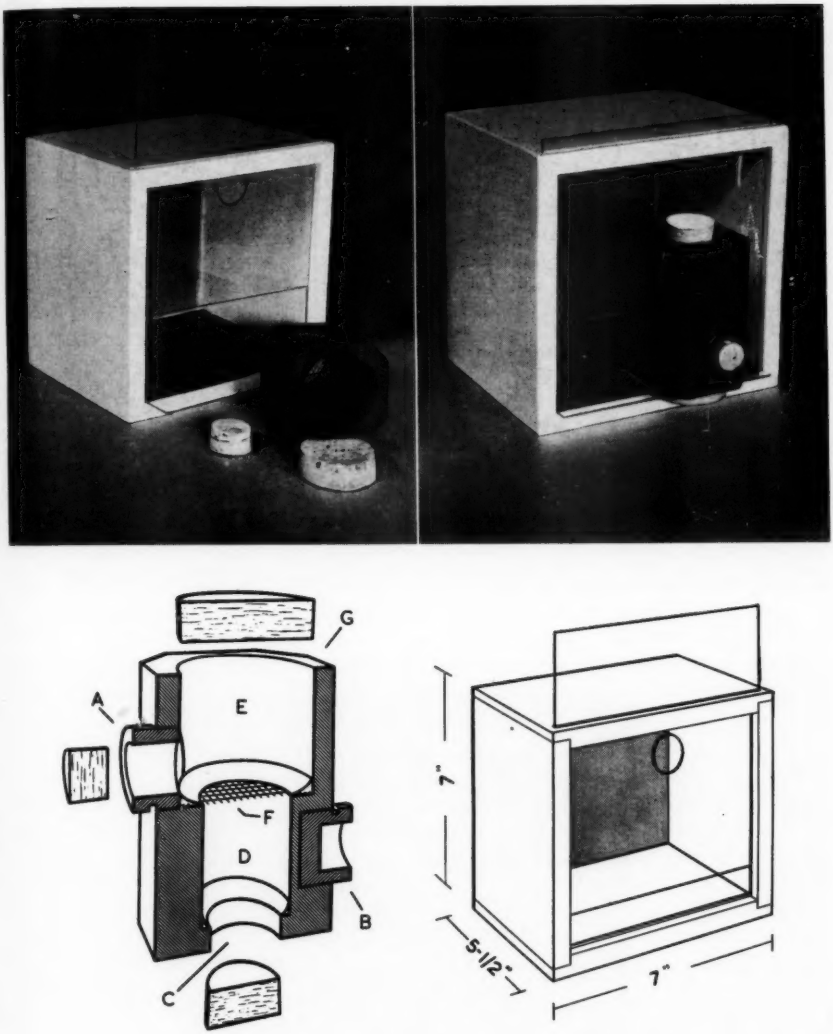
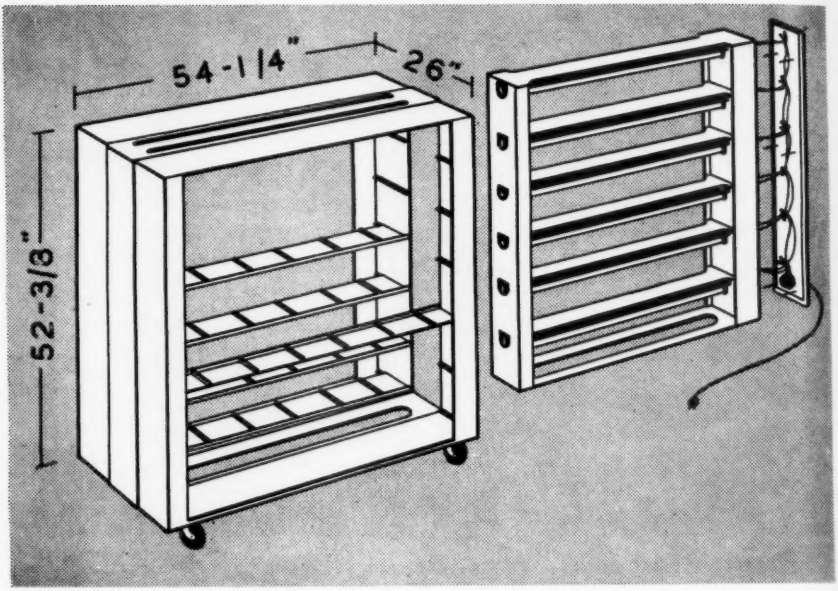


Fig. 2. Pupa container and fly cage. Upper, the components unassembled (left) and assembled (right). Lower left, a longitudinal section of pupa container. Lower right, dimensioning of fly cage.

stopped by the facings. The plastic fronts of the fly cages can then be raised without interference from the shelf above. The height and length of the center section are the same as for the shelf section, but the width is only 6½ inches. It is strengthened by horizontal supports between the ends of the frame and by facings similar to those on the shelf sections. The horizontal supports are directly opposite the shelves of the outer sections. The width of these supports and the width of the top of the frame are reduced over most of their length



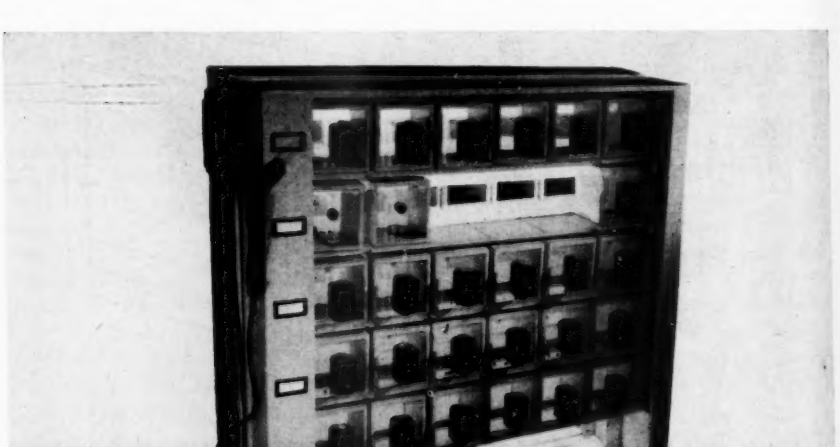


Fig. 3. Cage rack. Upper, rack in use. Lower, dimensioning of the shelf sections and the removable center section bearing the lighting units.

and an elongated opening is cut in the bottom of the frame to allow upward ventilation when the three units are assembled.

The wider facings on the service end of the section form part of a closed upright compartment that contains all the wiring. A removable panel, which completes this compartment, bears six switches that control the individual lights. A fluorescent light, 48 inches long, is mounted between the ends of the frame about three inches above each shelf. The main electrical circuit is controlled by a time switch, which may be set to turn the lights on and off according to a schedule. The two shelf sections are mounted on a base with sufficient space between them for the center section. Small drawer rollers between the base and the center section facilitate its insertion and removal. The rack is mounted on large rubber-tired casters and is enamelled white.

Discussion

The equipment and technique have been given a thorough trial. Over 200 lots of *P. affinis*, totalling approximately 7,000 larvae, have been cared for with satisfactory results. The equipment is simple and convenient to use. Handling of the insects, which is time-consuming and often results in injury or loss, has been reduced by at least 50 per cent and the rearing conditions are more uniform than the previous rearing techniques.

The cabinet for rearing larvae holds 600 test tubes in a small space. A person seated at a microscope can easily reach several thousand tubes and, as each numbered tube is held separately in a nearly horizontal position, individual tubes can be easily selected. This facility reduces handling and exposure to light, which is important because the larvae may stop feeding and wander from the food when exposed to light.

With the pupa container and fly cage the only manipulation required from the time the mature larvae are put into the sawdust until the flies gather in the cage is the inversion of the container to separate the pupae from the sawdust. As the pupae are collected from the sawdust without touching them, the chances of injury, which often results from damage to the fragile puparia during handling, are greatly reduced. The fly cage needs to contain only food and remains relatively clean, as the pupal debris is confined to the pupa container.

The cage rack provides about 45 linear feet of shelves to hold 72 fly cages in a floor space approximately two feet by 4½ feet with uniform illumination for each cage. The rack may be used in relatively close quarters and moved about for servicing, as it is independent of external light sources. The chances of accident and loss of flies are reduced because the cages are held in position on the shelves and the strong illumination attracts the flies to the rear when the front of a cage is opened.

Though this equipment was designed to fulfill special requirements in nutritional studies with small lots of *P. affinis* reared on different diets, the equipment or modifications of it may be used where similar rearing problems are encountered.

Summary

New equipment to hold larval rearing tubes, to handle pupae and adults, and to hold a number of cages is described. This equipment is simple, takes up little laboratory space, and facilitates techniques that eliminate much tedious, time-consuming care for small lots of dipterous insects in nutritional studies.

Acknowledgments

The authors acknowledge the helpful suggestions of Messrs. G. A. Denyes and C. F. Nicholls, the latter of whom also built the equipment and made the drawings. Mr. T. Stovell took the photographs.

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Insects Affecting Seed Production in Red Pine
III. *Eucosma monitorana* Heinrich, *Laspeyresia toreuta* Groté (Lepidoptera: Olethreutidae), *Rubsaamenia* sp. (Diptera: Cecidomyiidae), and Other Insects[1]

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Introduction

This paper describes the seasonal history and habits of the less important red pine cone insects, and presents notes on the predators, scavengers, and other insects that commonly inhabit infested cones. During 1950-1954, *Eucosma monitorana* Hein., *Laspeyresia toreuta* Groté, and *Rubsaamenia* sp. were rarely as abundant as the cone beetle, *Conophthorus resinosae* Hopk., (10) or *Dioryctria* spp. (11), although they contributed significantly to seed loss. Owing to the scarcity of these insects, some of the life history details remain incomplete.

In North America, insects of the genus *Eucosma* mine in the cones and shoots of coniferous trees, e.g. *E. sonomana* Kearf. in twigs of ponderosa pine, engelmann spruce (8), and jack pine (1), *E. bobana* Kearf. and *E. rescissoriana* Kearf. in shoots and cones of pines in the western United States (8), and *E. gloriola* Hein. in shoots of white pine (3) and red pine in the eastern United States and Canada. The genus *Laspeyresia* comprises many species that tunnel through the seeds of conifers and other trees, e.g. *L. youngana* (Kft.) in spruce (8) and *L. caryana* (Fitch) in hickory (3).

E. monitorana and *L. toreuta*, although they belong to the same family, differ considerably in habits. Larvae of *E. monitorana* feed on both the

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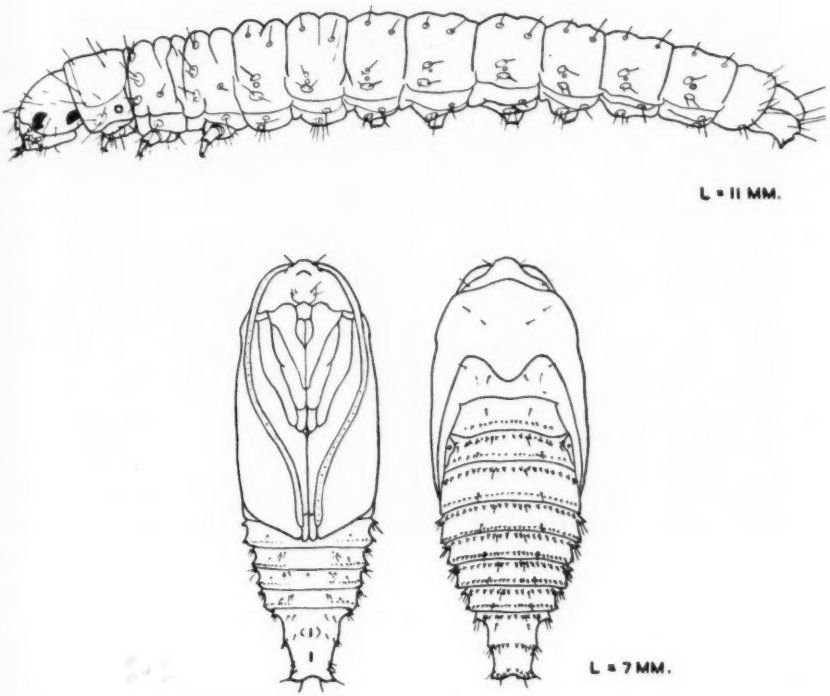


Fig. 1. Mature larva and pupa of *Eucosma monitorana* Hein.

seeds and scales of growing cones, and leave the cone before pupation. They are sometimes very effective in the natural control of the cone beetle, *Conophthorus resinosae* (10). Their damage causes the cone to wither and discolour but can be distinguished from that done by other cone insects. Larvae of *L. toreuta*, on the other hand, restrict feeding primarily to the seeds of fully grown cones, and, consequently, do not affect the shape, colour, or size of the cone. This species spends its entire life, except for the adult stage, in the cone and is further distinguishable by being probably the only cone insect encountered during the investigation that remains dormant through more than one winter. *Rubsaamenia* sp., the least destructive of the common red pine cone insects, was often found in cones that had previously been damaged by other insects.

***Eucosma monitorana* Heinrich**

This insect was not positively identified from red pine cones in Ontario until 1952, and its relative scarcity made it difficult to obtain sufficient material for rearing and observation. Seed loss attributable to this insect seldom exceeded 40%, and tended to be very localized. *E. monitorana* has previously been recorded from cones of "*Pinus* sp." in Pennsylvania and Virginia (4, 6), and, according to the Insect Systematics and Biological Control Unit, Entomology Division, Ottawa, in Quebec.

Description of Developmental Stages

Egg

Laid eggs were not observed, but ones dissected from gravid female adults were ovoid, orange, and about 0.75 mm. long.

Larva

The mature larva of *E. monitorana* is about 12 mm. long, greyish white, with the head and pronotum brown (Fig. 1). A complete series of preserved larvae was not available for head measurements, but cast head-capsules were easily separated into five size groups, indicating the presence of five instars, the approximate mean head widths of which are: instar I, 0.26 mm.; instar II, 0.42 mm.; instar III, 0.66 mm.; instar IV, 0.96 mm.; and instar V, 1.30 mm.

Head: in instars I to IV, grey-brown to light orange-brown; in instar V orange-brown, space bounded by ocelli black, another slightly smaller black or dark brown spot on edge of occiput posterior to ocelli.

Thorax: pronotum and legs light brown to grey-brown in instars I to IV, pale orange-brown in instar V; remainder of thorax like abdomen.

Abdomen: setal sclerites of instars I to IV light brown, conspicuous against white of rest of integument; sclerites of instar V cream and inconspicuous, remainder of integument cream to white, sometimes tinged dorsally with red; proleg crotchets uniserial and uniordinal in all instars; epiproct light brown to grey-brown in instars I to IV, cream in instar V.

Pupa

The pupa is about 7.5 mm. long and dark brown, with rows of posteriorly directed spines on the dorsal surface of the abdomen (Fig. 1).

Adult

The adult, fully described by Heinrich (6), is a reddish-brown moth with tan and silver markings on the forewings (Fig. 2). The wingspan is about 15 mm.

Seasonal History

Cone damage begins in early or mid-June when first-instar larvae bore into the upper part of the second-year cone, leaving minute holes from which a small amount of light brown frass is ejected. Within the cone they tunnel more or less straight down the face of the scale toward the cone axis, where they feed on immature ovules. There are sometimes 25 or more young larvae per cone, which suggests that the eggs are probably deposited on or very close to the cone. Larvae continue to feed inside the cone as long as there is edible material, and may sever the cone axis at the base, causing the cone to drop. The remaining stub differs from that left after attack by *Conophthorus resinosae* in being longer and in lacking a transverse groove at the distal end (10).

About the end of June, mature larvae of *E. monitorana* may often be found in relatively fresh cones that reveal no evidence of damage by young larvae. Apparently, fourth-instar larvae migrate from cones that have become overcrowded or been consumed. These "second" cones, which bear oblong entrance holes 1-2 mm. long between the upper scales, seldom contain more than five larvae apiece. Judging from the course of larval tunnels, the fourth-instar larva tunnels circumferentially beneath the surface of the cone over the width of several scales and then bores toward the cone axis, where it moults. The fifth-instar larva then assume a longitudinal position in the cone axis and feeds upon the surrounding ovules.

Fig. 2. Adult of *Eucosma monitorana* Hein. on a second-year red pine cone.

Infested cones remain moist and green for about a week after initial attack but then shrink and discolour until they are hard and brown. In contrast to red pine cone borers of the genus *Dioryctria* (11), larvae of *E. monitorana* seldom eject their frass from the cone but pack it tightly into old burrows. Infested cones contain little or no webbing, such as is ordinarily produced by other cone-inhabiting Lepidoptera.

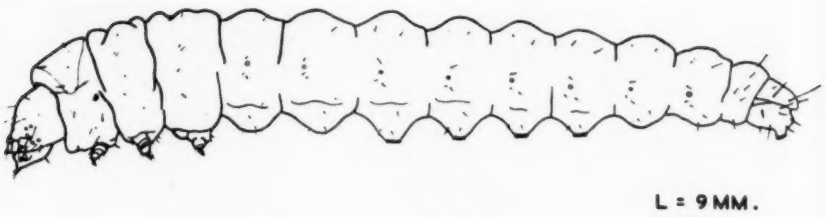
Fully grown larvae of *E. monitorana* leave infested cones beginning about mid-July. In rearings the larvae always left the cone and pupated in thin, debris-coated cocoons about 10 mm. long at the bottom of the container. Although much time was devoted to looking for them, no pupae were found under natural conditions and it is suspected that this species pupates in the soil beneath infested trees.

E. monitorana overwinters as a pupa, the adult emerging the following May. In 1953, after the pupae had overwintered at 0°C, adults emerged during a seven-day period (May 5 to 11), with emergence of males virtually completed before that of females began. Attempts to induce reared adults to mate and oviposit in the laboratory were unsuccessful.

Natural Control

Only a few cases of parasitism and of predation of *E. monitorana* were recorded during the investigation, but examination of infested cones repeatedly indicated that many very young larvae died while tunnelling down the face of the cone scales. Mortality of larvae in rearings was usually slight, but many pupae failed to survive artificial overwintering at 0°C.

Larvae of the braconid parasite *Apanteles* sp. (near *tischeriae* Vier.) emerged from mature *E. monitorana* larvae in July, at Angus, Ontario. Adult



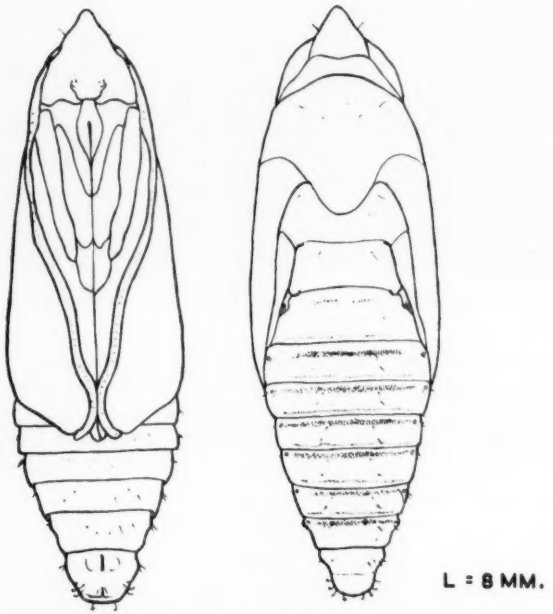


Fig. 3. Mature larva and pupa of *Laspeyresia toreuta* Grt.

parasites appeared in late July and early August, after spending nine or ten days in their cocoons. One adult of the ichneumonid parasite *Calliephialtes comstockii* (Cress.) was reared from a mature *E. monitorana* larva at Thessalon, Ontario, in late August, 1954.

Larvae of the melyrid beetle *Attalus nigrellus* (Lec.) preyed on *E. monitorana* larvae in cones but mortality was light.

Laspeyresia toreuta Groté

In Ontario, *L. toreuta* infests second-year cones of both jack pine and red pine. This insect is rarely so injurious to red pine seed production as the preceding species, and is the only red pine cone insect that causes seed loss without appreciably injuring the cone. It has been reported from cones of *Pinus virginiana* Mill. in Pennsylvania, the District of Columbia, Virginia, North Carolina, and Texas (7); from "yellow pine" in New York (4); from *P. taeda* L. in Virginia and North Carolina (9); from *P. contorta* Dougl. and *P. banksiana*

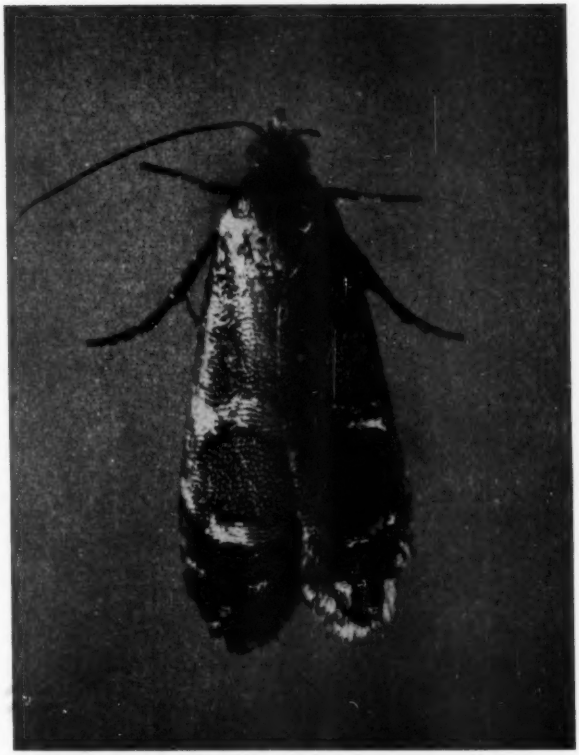


Fig. 4. Adult of *Laspeyresia toreuta* Grt.

Lamb. in Saskatchewan (5); and also occurs in California, Oregon, Idaho, and Montana (13), in New Jersey and Georgia[1], in Maryland[2], and in Quebec[3].

Description of Developmental Stages

Egg

Freshly deposited eggs are pearly white, translucent, thin-walled, ovoid, and about 0.30 x 0.18 mm. in size, with the surface finely roughened. They thus differ considerably from the eggs of *L. youngana* (Kft.) as described by Tripp (15), which are pale orange, nearly spherical, and about 0.5 mm. in diameter.

Larva

The mature larva of *L. toreuta* (Fig. 3) is about 10 mm. long and is yellowish white with the sclerotized parts pale brown. The thoracic segments are considerably wider than the head, which is partly retractable within the prothorax. The number of larval instars remains somewhat doubtful, owing to the small number of larvae available for study. However, measurements of head capsules suggest the presence of four instars, with approximate mean head widths of 0.14 mm., 0.32 mm., 0.66 mm., and 0.90 mm.

[1]Personal communication, Academy of Natural Sciences, Philadelphia.
[2]Personal communication, United States National Museum, Washington.
[3]Personal communication, Insect Systematics and Biological Control Unit. Entomology Division, Ottawa.

Head: in instars I to III grey-brown; in instar IV orange-brown to dark brown, genal marks obscure to prominent.

Thorax: pronotum grey-brown in young larvae, pale brown later; legs grey-brown in instars I to III; colourless to dark brown in instar IV; remainder of integument white.

Abdomen: white, unmarked; setae short and inconspicuous; proleg crochets uniserial and uniordinal.

Pupa

The pupa (Fig. 3) is slender, pale amber, 6-8 mm. long, with rows of small spines on the dorsal surface of the abdomen. In contrast to the rounded head of the pupa of *L. youngana* (Kft.), as illustrated by Tripp (15), the head of the *L. toreuta* pupa is projected into a point.

Adult

The adult of *L. toreuta* (Fig. 4), fully described by Heinrich (7), is a grey-brown moth with a wing expanse of 13 to 15 mm. Two prominent black-bordered silver bands cross the forewing.

Seasonal History

Adults emerge during the second half of June from previously infested cones. At Sault Ste. Marie in 1951, emergence of males was completed in four days (June 17-20), but that of females took 12 days (June 18-29). Neither mating nor oviposition was observed in the field, but eggs were found in crevices on all parts of the cone surface.

Cone attack begins in early July when first-instar larvae bore into the upper part of second-year red pine cones, leaving extremely minute holes near the line separating adjacent cone scales. Entrance holes cannot be seen with the naked eye. The cone by this time, although almost fully grown, is still green and moist, and the seeds and scales inside are pale. Some larvae enter at the upper edge of the exposed part of the scale (apophysis) and mine slightly below the surface of the inner face to the seeds at the base of the scale. Other larvae enter near the lower edge of the apophysis and bore directly to the inner face of the scale before mining towards the seeds. When it approaches a seed the larva returns to the surface of the scale, enters the distal end of the seed through the seed wing, tunnels between the soft endoderm and the hard seed coat to the proximal end of the seed, and begins feeding on the immature embryo. A larva that encounters an aborted seed at the base of the scale continues to tunnel through the cone until it reaches a suitable seed. Larval mines, which usually follow a twisting path, turn brown and are thus distinguishable against the pale green of the scale until the cone begins to dry and darken at maturity.

Larvae feed in the original seed during the first three instars, and then tunnel circumferentially through the bases of nearby scales, consuming from three to nine more seeds. The mature larva ceases feeding in late August or early September and, in preparation for overwintering, constructs a short, usually diagonal, tunnel into the woody axis of the cone (Fig. 5). This tunnel is extended outward into a previously consumed seed, and only a thin, easily penetrable layer remains closing off the tunnel from the outside of the seed. By this time the scales of red pine cones have begun to separate for the release of seeds. However, in jack pine cones, the scales of which remain tightly closed together, the larva tunnels to near the surface of the cone, rather than into a seed.

Fig. 5. Longitudinal section of a mature red pine cone containing a larva of *Laspeyresia toreuta* Grt. in a tunnel in the axis.

When the cone opens, damaged seeds are held securely in place by the hardened fecal matter that fills the larval burrows. The wings of damaged seeds are held flush against the back of the scale above, in contrast to the loosely held wings of undamaged seeds, and this characteristic is often useful in determining whether a cone is infested. Larval feeding has no discernible effect on the size or shape of the cone.

Some *L. toreuta* pupate in May of the year following cone attack and become adults in June; others remain as larvae for a further 12 months. Before pupating the larva lines its tunnel with silk. Empty pupal cases are left protruding from exit holes in the seeds.

The degree of delayed emergence varies from year to year, and between localities in the same year. For example, first-year emergence of adults was only 8% at Chalk River in 1951, but at Camp Borden it was over 80% in 1951 and about 50% in 1952. Delayed emergence among other cone insects is well known (12, 15) and is generally considered as an adaptation to ensure survival in the event of complete cone crop failure, which occasionally occurs.

The abundance of *L. toreuta* larvae and that of sound cones, which together determine population density, are controlled by factors whose operation can

only be stated here in general terms. Owing to delayed emergence, by which part of the population remains dormant until the second spring, the abundance of larvae in any one year is determined by the size of the populations of the two preceding years, and the degree of emergence from them. The availability of cones for infestation by *L. toreuta* depends basically on the original size of the red pine cone crop, but since *L. toreuta* infests only sound cones, it is greatly affected by the cone loss that occurs before July, i.e. before cone attack by *L. toreuta* begins. The amount of this early loss, most of which is caused by other cone insects, depends in turn on the proportion of these other insects surviving from the previous year. Relatively light early damage leaves many sound cones, and the density of *L. toreuta* larvae per cone consequently tends to be low. Conversely, when early damage is heavy, only a few suitable cones remain for *L. toreuta*, and larval density, accordingly, tends to be high. However, delayed emergence of *L. toreuta* can completely alter the latter situation, as demonstrated in the following example. The number of second-year cones in a group of open-grown red pines at Chalk River in 1952 was considerably lower than in 1951, and almost all were destroyed in June by the cone beetle *Conophthorus resinosae* so that very few sound cones remained for subsequent infestation by *L. toreuta*. The remaining cones, which should have become densely occupied, in fact sustained only moderate injury. Later examination of the cones that had been infested in 1951, and which were one of the two sources of the 1952 population, showed that there had been negligible emergence, i.e. almost all of the 1951 population had remained dormant for a second year. The degree of emergence in 1952 of the 1950 population was not determined but is believed to have been small. Although it would be unsafe on so little evidence to postulate any real connection between the degree of delayed emergence of *L. toreuta* and the abundance of cones left after damage by other insects, it is apparent in this case that *L. toreuta*, by remaining dormant during 1952, avoided a severe shortage of cones.

The number of *L. toreuta* larvae per infested cone varies from one to 12, depending on the conditions already mentioned, but the larvae are not distributed equally throughout the available cones. Instead, there tends to be more than one larva per cone, and the proportion of infested to uninfested cones is hence lower than it would otherwise be.

Natural Control

Parasites, which kill only mature larvae, were the main cause of mortality of *L. toreuta* in the cone, although a few half-grown larvae died for no obvious reason while tunnelling from seed to seed. Some infested cones were observed to contain as many as 25 larval entrance holes but less than half as many established larvae. Dead first-instar larvae were never found on the surface of the cone, and it was not established whether some of the holes were made by larvae that died in attempting to enter the cone or by ones that later entered through other holes. Except for one record of cannibalism, no mortality could be attributed to overcrowding in the cone. Red squirrels commonly remove and consume mature red pine cones in late summer and autumn, with consequent mortality to *L. toreuta* larvae. However, it was noticed at Camp Borden that a few infested cones removed by squirrels were only partly consumed, as though the squirrel had stopped dismantling the cone for seeds as soon as *L. toreuta* larvae became exposed.

Fully grown *L. toreuta* larvae in red pine cones were killed about the time they would normally have pupated, whether after one or two years in the

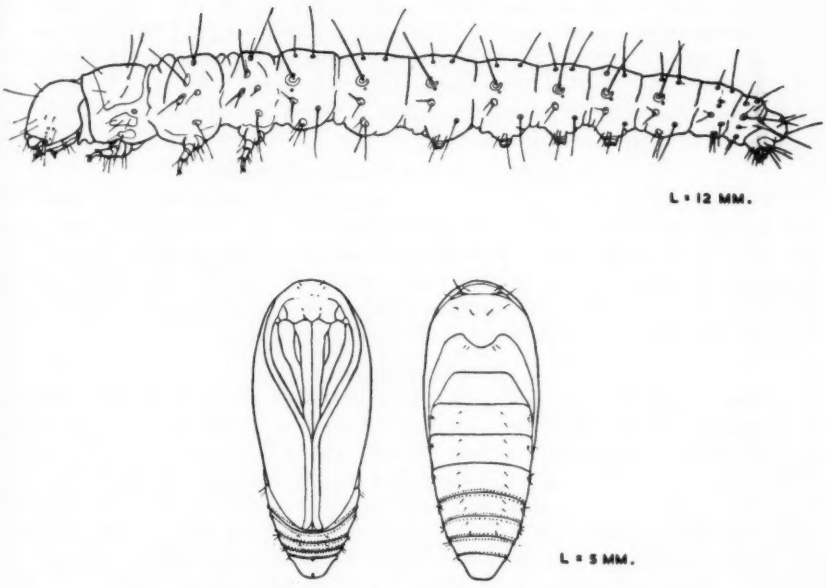


Fig. 6. Mature larva and pupa of *Holcocera immaculella* McD.

cone, by the braconid parasite *Phanerotoma* sp. (near *laspeyresiae* Roh.), adults of which left the cone during June and July. Mortality resulting from this parasite was 38% at Sault Ste. Marie in 1951 and 26% at Chalk River in 1952. According to Muesebeck *et al.* (13), *P. laspeyresiae* parasitizes *L. toreuta* in Oregon, Idaho, Montana, and California.

Larvae of the ichneumonid parasite, *Calliephialtes comstockii* (Cress.) emerged from mature larvae of *L. toreuta* at about the same time as *Phanerotoma* sp. and pupated nearby in white cocoons. All the specimens that were recovered had spent only one winter in the cone. Adults appeared during June at Camp Borden in 1953.

Because their damage to cones is not easily recognizable, cones containing *L. toreuta* larvae are taken, along with undamaged ones, during collection for seed extraction, and it was at one time feared that this practice might bring about the accumulation of a heavy *L. toreuta* population in the vicinity of the Tree Seed Plant at Angus, Ontario. However, an examination of infested cones that had been subjected to seed extraction at Angus revealed that no *L. toreuta* larvae survived the process, which involves exposure to temperatures of 160-170°F. for 2½ hours at 10-20% R.H. This problem did not arise with red pine cone insects whose damage is obvious.

Rubsaamenia Sp.

The great difficulty that was encountered in rearing this cecidomyiid to maturity delayed its positive identification until 1954. Until then it had been dubiously referred to as *Asynapta* sp., but Dr. R. H. Foote, United States Department of Agriculture, Washington, D. C., determined it to be a new and undescribed species of *Rubsaamenia*, other specimens of which had been

collected from cones on the Pacific coast. Dr. Foote also stated that the latter specimens are inquilines, i. e. they inhabit cones damaged by other insects. *Rubsaamenia* sp. observed in red pine cones during the present study was partly inquilinic but also infested otherwise-undamaged cones. Damage by this insect to red pine cones in Ontario during 1950 to 1954 was usually very light but on a few occasions exceeded 40%.

Description of Developmental Stages

Young maggots are about 0.5 mm. long, slightly dorso-ventrally flattened, and almost colourless. Mature maggots (Fig. 7A, B) are about 2 mm. long and vary from orange-pink to bright red-orange. The posterior end of the abdomen is armed with a pair of short, upwardly curved, sclerotized spines. Pupation occurs within the brown, sclerotized puparium. The adult is a delicate fly with a pink abdomen and clear wings.

Seasonal History

Cone attack begins in June but infested cones are at first very difficult to recognize. Some apparently normal second-year cones contained as many as 100 minute transparent maggots between the scales and around the seeds. Often the only external sign of injury is a slight withering and shrinking of a few scale tips, but very heavily infested cones wither noticeably and the scales separate prematurely. The maggots feed only on the surface of scales and seeds, which turn brown and appear to have been slightly scraped or gouged. There are seldom more than 25 mature maggots per cone, and these feed most often in the space between scales, rather than around the seeds. Mature *Rubsaamenia* sp. maggots possess the well-known cecidomyiid habit of leaping, and can cover several inches at one leap. Most mature maggots leave the cone in mid-summer but a few remain and overwinter within the puparium. The few adults that were obtained emerged from rearings in early summer.

Infested cones exude resin, which eventually crystallizes into white flakes between the scales. Cone damage can usually be diagnosed afterwards by these resin flakes, and by the absence of debris such as that left by larvae of cone beetles and cone worms.

Natural Control

Rubsaamenia sp. in Ontario was parasitized by *Tetrastichus* sp. (near *hunteri* Cwfd.) (Hymenoptera: Eulophidae), adults of which emerged from host puparia in spring or early summer.

Other Insects

***Rhyacionia buoliana* (Schiff.) (Lepidoptera: Olethreutidae)**

Within its range in Ontario, the European pine shoot moth often destroys second-year red pine cones on young trees and on the lower branches of larger trees. The damage usually causes severe distortion of the growing cone and a copious flow of resin, which later hardens into a yellowish lump around the injured part of the cone.

***Holcocera immaculella* McD. (Lepidoptera: Blastobasidae)**

This was the dominant secondary, or inquilinic, lepidopteran found in red pine cones in Ontario during 1950-1954 and was previously reported by Raizenne (14) from pine cones in Simcoe County. According to the Insect Systematics and Biological Control Unit, Ottawa, *H. immaculella* feeds on white spruce in Ontario and is recorded also from Nova Scotia, Quebec, and British Columbia.

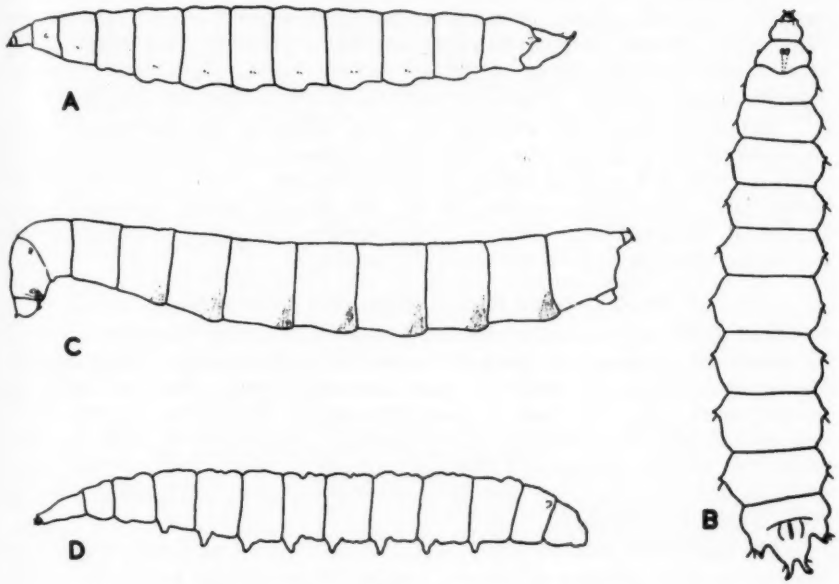


Fig. 7. Larvae of Diptera from red pine cones.
A. *Rubsaamenia* sp., lateral view;
B. *Rubsaamenia* sp., ventral view;
C. *Oscinella* sp., lateral view;
D. *Lestodiplosis* sp.

The larva is 10 to 12 mm. long when mature, with a reddish-brown head and a brown abdomen lined with grey (Fig. 6). There are apparently five larval instars, with approximate head widths of 0.22 mm., 0.31 mm., 0.46 mm., 0.72 mm., and 1.05 mm. Young larvae are pale brown and gradually assume the markings of the final stage. The head is orange-brown to reddish-brown, and marked. The pronotum is orange-brown and paler than the head, and the remainder of the thorax is marked like the abdomen. The thoracic legs are pale brown. The abdomen is basically brown, with the following irregular grey stripes: (a) a narrow mid-dorsal stripe; (b) a broader and paler latero-dorsal stripe; (c) a still broader and more conspicuous stripe immediately dorsad of spiracles; and (d) a faint, narrow, latero-ventral stripe. The ventral surface of the abdomen is paler than the dorsal. The setal sclerites are pale to dark brown, that of seta rho on first seven abdominal segments being crescentic and open dorso-posteriorly. Seta rho of eighth segment is filamentous. The epiproct is yellow-brown.

The pupa is 4 to 6 mm. long, reddish-brown, and compact, with the ends bluntly rounded (Fig. 6). The adult is uniformly pale brown and has a wing expanse of about 14 mm.

H. immaculella overwinters as a pupa in dense webbing spun in old red pine staminate flower clusters and in dead second-year red pine cones. Adult emergence was not observed under natural conditions, but the earliest larvae were usually found during June in recently damaged cones and in staminate

flower clusters. The larvae in flower clusters spun webbing among the individual strobili, which, as a result, remained attached to the shoot long after pollen release. Larvae in cones seemed to feed on both deteriorating cone tissues and the larvae of primary cone insects, particularly those of *Conophthorus resinosae*. Pupation occurred in late August and September.

Mature larvae of *H. immaculella* were killed in late summer by two undescribed species of the braconid genus of *Apanteles*, larvae of which emerged from the host and pupated nearby in white cocoons. Adults appeared several weeks later. According to Dr. W. R. M. Mason, Insect Systematics and Biological Control Unit, Ottawa, these parasites are closely related to *A. aristoteliae* Viereck and *A. californicus* Muesebeck.

***Duvita vittella* Bsk. (Lepidoptera: Gelechiidae)**

During the present study, this insect was found mainly in cones killed by *Conophthorus resinosae*, in which its larvae fed on dead tissues. Craighead (3) has reported this species, under the name *Battaristis vittella* (Bsk.), as occurring in the cones, galls, and buds of pines throughout the eastern United States, and records that it sometimes causes damage, presumably to buds, in pine plantations in New England. Forbes (4) records *D. vittella* from stunted cones of Scots and Austrian pines and from cecidomyiid galls on loblolly pines in New York and Maryland.

The mature larva of *D. vittella* is slender and from 4 to 6 mm. long. The head varies from chestnut-brown to orange, the pronotum is a paler brown than the head, and the epiproct is very pale brown. The abdomen is grey to white and semi-transparent, with the setae barely visible. The gonads of male larvae are reddish and visible externally. The pupa is pale brown and about 4 mm. long. The adult has a wing expanse of 8 to 10 mm., and the forewing is cinnamon-brown traversed by grey bands. A conspicuous feature of living adults is the bright redness of the eyes, which, however, darkens rapidly after death and is barely noticeable in pinned specimens.

Young larvae begin feeding between the scales of dead second-year red pine cones in mid-summer. Partly-grown larvae overwinter inside the cone and resume development the following spring, reaching maturity about June. Before pupating, the larva spins webbing about itself and across the opening of a convenient tunnel to the outside of the cone. At Sault Ste. Marie, in 1954, adults appeared during June. Small cones containing larvae of *D. vittella* tend to fall to pieces but larger cones are not so affected.

D. vittella larvae in red pine cones were parasitized by *Copidosoma nanellae* Amer. authors (Hymenoptera: Encyrtidae) and an *Apanteles* species near *californicus*. *C. nanellae* larvae pupated inside the mature host larva, causing conspicuous bulges on the surface. During July 1954 at Sault Ste. Marie, 42 adults emerged from one host larva and 23 from another. Larvae of *Apanteles* sp. pupated in tough silk cocoons, after leaving the mature host larvae. Of the only two adults recovered (1954), one emerged in late June at Sault Ste. Marie and the other in late July at Midhurst.

***Moodna ostrinella* Clemens (Lepidoptera: Phycitidae)**

Forbes (4) records *M. ostrinella* from sumac heads and acorns in New York, Pennsylvania, and Texas. Raizenne (14) lists one dipterous and six hymenopterous parasites from this species on sumac in southern Ontario. Larvae in red pine cones are 8 to 10 mm. long when mature and plain yellow-

grey with a greenish tinge. They feed on the tissues of second-year cones damaged by other insects, overwinter in the cone, and pupate in the following spring. The only adult recovered emerged in early June.

***Recurvaria* spp. (Lepidoptera: Gelechiidae)**

Larvae of two species of *Recurvaria* were identified in damaged cones. They were variously patterned with bright red on a white background and attained a length of 6 mm. Both species fed on dead cone tissues and occasionally killed larvae and pupae of *Conophthorus resinosae*, but more commonly they inhabited red pine staminate flowers, where they seemed to feed on pollen. Adults appeared in mid-summer.

***Pityophthorus* spp. (Coleoptera: Scolytidae)**

Pityophthorus pulicarius Zimm. and *Pityophthorus* sp. (probably *puberulus* Lec.) occasionally bred in red pine cones and shoots that had been killed by *Conophthorus resinosae*. Since these insects attack living twigs (2), they are a menace to young cones.

***Oscinella* sp. (near *conicola* (Green)) (Diptera: Chloropidae)**

This fly fed coprophagously in dead red pine cones, especially in those killed by *C. resinosae*. The minute white maggots (Fig. 7C) reached maturity in the spring of the year following cone damage and formed compact, golden puparia about 1 mm. long inside the dead cone. Adults emerged during June and July.

***Lestodiplosis* sp. (Diptera: Cecidomyiidae)**

Orange, elongate, cylindrical maggots of this species (Fig. 7D) appeared in red pine cones shortly after the beginning of damage. They were most abundant in cones killed by *C. resinosae*, in which they preyed on larvae and pupae of the cone beetle. Pupation occurred in thin silk cocoons in crevices at the end of withered cone scales. Adults, which have pale blue spots on the wings, emerged during June and July.

***Leucopis* sp., *Cnemodon coxalis* Cur., and *Lycoria pauciseta* (Felt)**

Leucopis sp. (near *piniperda* Malloch) (Agromyzidae) and *Cnemodon coxalis* Cur. (Syrphidae) were occasionally found on the outside of second-year cones, but their relation, if any, to other cone insects was not ascertained. *Leucopis* sp. was parasitized by *Pachyneuron altiscutum* How. (Hymenoptera: Pteromalidae). Larvae of *Lycoria pauciseta* (Felt) (Sciaridae) fed in wet, rotting cones previously killed by *Eucosma monitorana* Hein. Adults appeared in mid-August.

Acknowledgments

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(Received June 1956)

North American Components of the Genus *Diasemia* of Authors (Lepidoptera: Pyralidae)[1]

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Work undertaken in connection with Mr. C. P. Kimball's projected list of Florida Lepidoptera has revealed a number of problems in the North American species usually referred to *Diasemia* Hübner ([1824-25] p. 348), type *Pyralis literalis* Denis and Schiffermüller (=*Phalaena litterata* Scopoli) (Figs. 1, 2). A structural study shows that these species belong to five groups, generically distinct from one another and from the type species of *Diasemia*. *Diasemia alaskalis Gibson* (Fig. 3) is congeneric with *Udea ferrugalis* (Hübner) and should be known as *Udea alaskalis* (Gibson), new combination. I have characterized the genus *Udea* Guenée in an earlier paper (Munroe, 1950). *Diasemia plumbosignalis* Fernald (Fig. 10) and related species belong to the genus *Choristostigma* Warren, 1892: 440. The species of *Choristostigma* will be discussed in a separate publication. *Diasemia magdalena* Fernald and an undescribed species belong to the genus *Daulia* Walker (1859: 975) hitherto known from the tropics of the Old World and from Argentina. *Hydrocampa ramburialis* Duponchel and *Desmia? janassialis* Walker require new genera.

Genus *Daulia* Walker

Type species: *Daulia afralis* Walker (Figs. 4, 5)

Daulia was placed by Hampson in the Nymphulinae, on the ground of the supposed stalking of R_2 with R_{3+4}. I have examined three specimens of *Daulia afralis*: one has R_2 stalked on both sides, the other two have R_2 free on both sides. One specimen of *D. subaurealis* (Walker) has R_2 free, one of *D. aurantialis*

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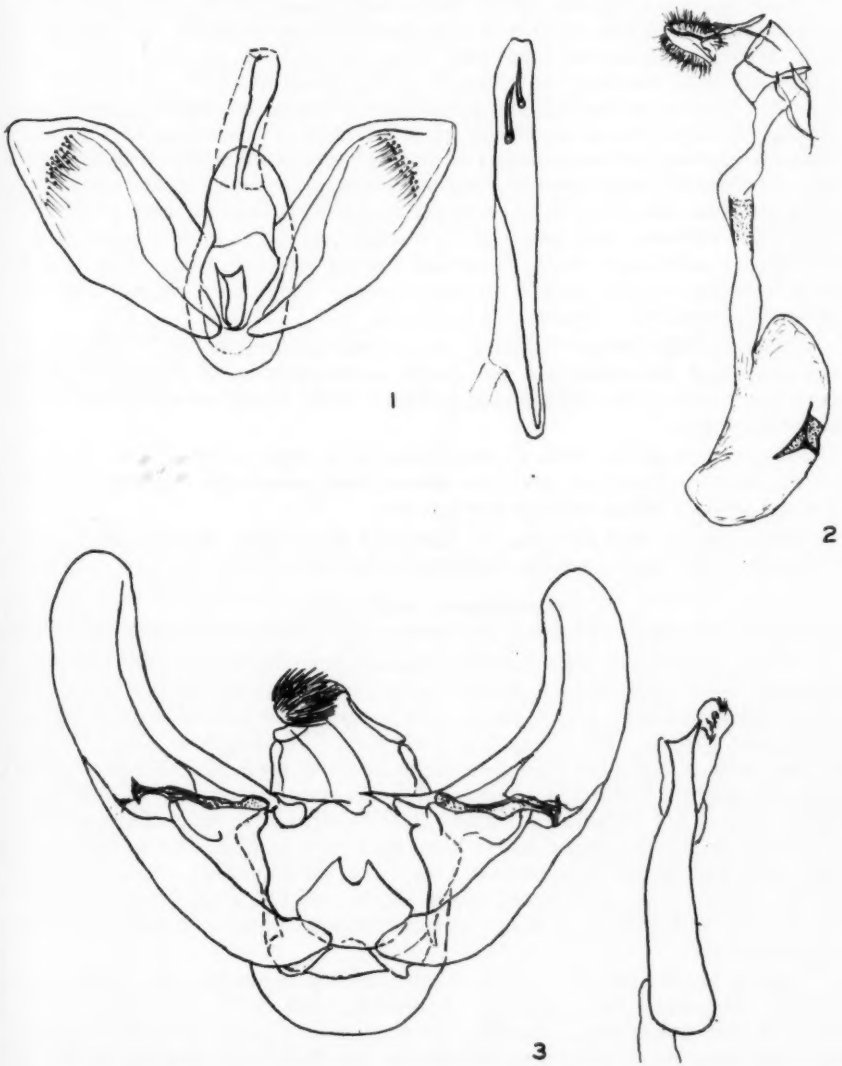
Hampson has R_2 stalked on both sides. Evidently this is an unstable character in the group. *D. aurantialis* has much shorter palpi and somewhat longer antennae than other species examined, but its genitalia are of the normal type (Fig. 6) and I leave it in the genus for the time being. *Daulia magdalena* (Fernald), new combination, has R_2 free, but the wing venation is otherwise typical and the genitalia are of the *Daulia* type (Fig. 7). *D. magdalena* was described from material from Florida and Texas. I restrict the type locality to Florida, from which state I have several specimens that agree well with the original description.



Figs. 1-3. Genitalia. 1, *Diasemia litterata* (Scopoli), ♂. 2, the same, ♀. 3, *Udea alaskalis* (Gibson), ♂.

Another species of the genus occurs in Arizona. This species differs from others of the genus in having M_2, M_3 and Cu_1 well separated in both fore and hind wings. Normally these arise close together, and in the hind wing the basal portions of M_2 and M_3 are weakly approximated. However, as the genitalia and habitus are closely similar to those of other species, and especially to those of *D. magdalena*, a generic separation seems unnecessary.

***Daulia arizonensis*, new species**

Figs. 8, 9

Labial palpus long, dull yellow dusted with fuscous; frons dull yellow with a white line on each side adjacent to eye; vertex, dorsum of thorax, and fore wings dull yellow; remainder of insect pale straw-coloured. Fore wing above with golden and black markings, as follows: a golden streak parallel to and just below Cu from base to antemedial line; an obscure, oblique, antemedial, golden line, running outward from costa, sharply offset inward as it crosses Cu, then running obliquely outward to inner margin at middle; some black scales along its outer edge; considerable irregular golden and black dusting in space between antemedial and postmedial lines, more or less arranged in streaks parallel to veins; postmedial line golden with some dark scaling along its edges, parallel to outer margin, hardly indented on submedian fold; subterminal line golden with some black scaling along its edges, regular, parallel to outer margin; fringe pale. Hind wing and under side unmarked. Expanse: 14 to 18 mm.

Male genitalia: uncus triangular, longer and sharper than in *D. magdalena*; valve expanded and rounded at tip; clasper shorter than in *D. magdalena*; penis much more robust, the single cornutus shorter, only about one-third the length of the aedoeagus.

This species differs from *D. magdalena* in its larger average size, its more pointed fore wings and its much less definite basal and medial markings, as well as in the genitalic characters mentioned above.

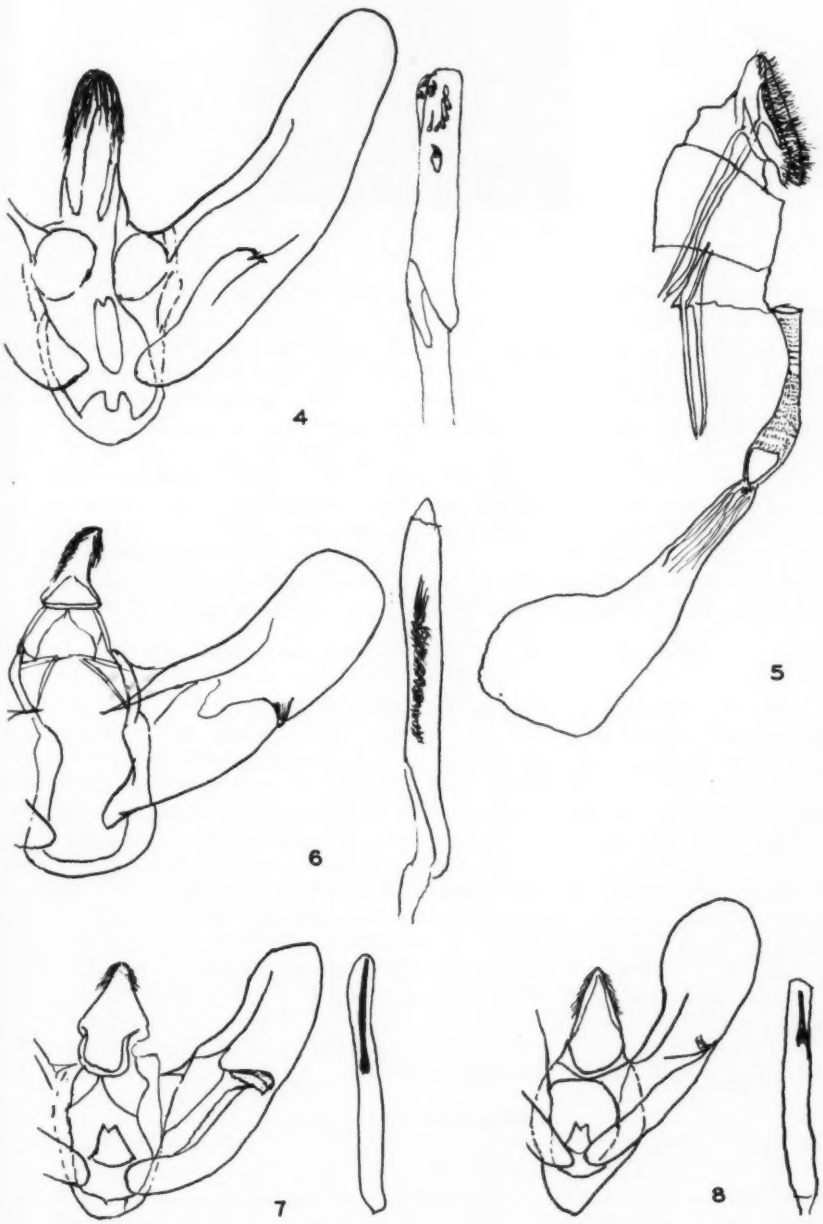
Holotype, ♂, and allotype, ♀, Huachuca Mts., Ariz., June 1, 1933, J. A. Comstock. No. 6412, Canadian National Collection.

***Diasemiopsis*, new genus**

Type species: *Diasemiopsis ramburialis*, new combination=*Hydrocampa ramburialis* Duponchel

Frons oblique, somewhat flattened; labial palpus with second joint obliquely upturned, third joint exposed, porrect, lying along the long anterior scaling of second joint; maxillary palpus short, with a small distal tuft of scales; antenna slender and filiform. Fore wing cell about three-fifths length of wing; R_1 and R_2 free; stalk of R_{3+4} less than free length of those veins; R_5 from just below angle of cell; M_1 from well below angle; cell sharply truncate, discocellulars hardly curved; M_2, M_3 and Cu_1 arising close together near lower angle of cell; Cu_2 arising from cell at two-thirds of cell-length from base; no obvious anal loop. Hind wing with Sc and R_s anastomosed for a short distance; discocellular strongly bent in middle; lower angle of cell acute; M_2, M_3 and Cu_1 arising close together, the last two approximated at base; outer margin waved and scalloped, especially in posterior part.

Male genitalia (Fig. 11): uncus slender, distally expanded and armed with anteriorly directed spines; tegumen moderately wide, its lateral parts broad; vinculum with lateral parts somewhat contorted, ventral part a straight transverse bar; juxta long, its ventral part rhomboidal, its dorsal part linguiform; valve ovoidal, its costa narrowly tubular; penis slender, armed with one stout cornutus and a row of slender ones.



Figs. 4-8. Genitalia of *Daulia* spp. 4, *D. afralis* Walker, ♂. 5, the same, ♀. 6, *D. aurantialis* Swinhoe, ♂. 7, *D. magdalena* (Fernald). 8, *D. arizonensis* Munroe.

Fig. 9. *Daulia arizonensis* Munroe, x 2.

Female genitalia (Fig. 12): simple, bursa small and short-necked, with a ribbon-like signum.

All authors from Guenée onward have associated *ramburialis* with *Diasemia litterata*, though Pierce and Metcalfe (1938) noted there was considerable difference in the genitalia of the two species. Actually *ramburialis* differs from *D. litterata* in a number of characters, among which may be mentioned: maxillary palpus with small tuft, not large flat-topped one as in *Diasemia*; labial palpus short, oblique, with third joint exposed, not long, porrect, with third joint concealed; cell of fore wing short and truncate, not long with posterior angle acute; M_2, M_3 and Cu_1 of fore wing arising close together, not well spread; M_3 and Cu_1 of hind wing approximated at base, not well separated; male with well-developed uncus, not with uncus suppressed; female genitalia with small bursa, short ductus, and ribbon-like signum, not with large bursa, long ductus and quadrate signum.

Diasemiopsis leodocusalis (Walker), new combination

Figs. 13, 14

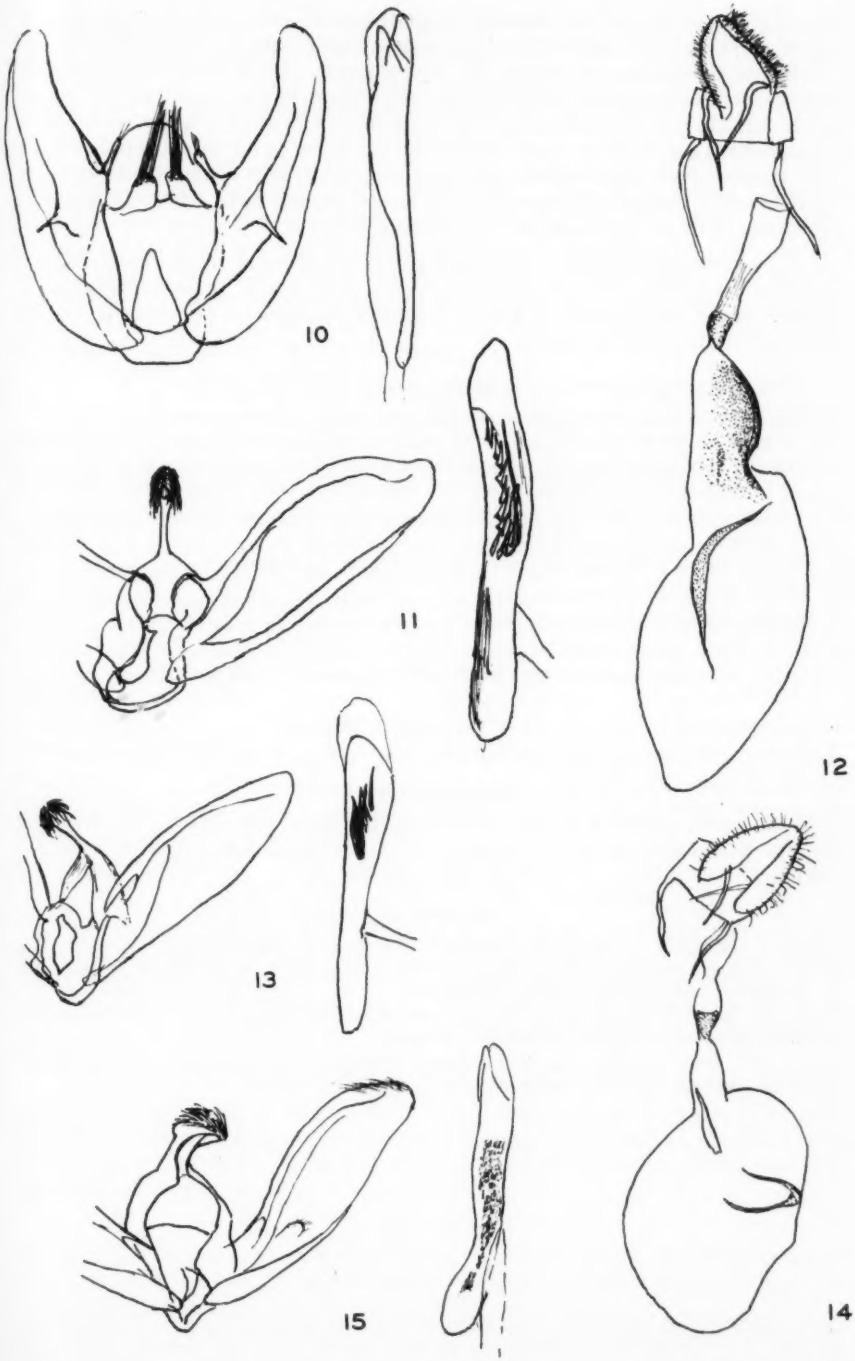
My identification of *D. ramburialis* is based on specimens from southern Europe and is probably reliable. Material from Florida shows pronounced differences in both male and female genitalia, the male having only a small number of slender cornuti instead of a long row of them as in *ramburialis*, and the female having the ductus bursae weakly sclerotized, not heavily so as in *ramburialis*. These specimens do not differ greatly in maculation from European specimens, but their average size is considerably smaller (about 13 mm. against about 20 mm.). The name *leodocusalis* was based on a U.S. specimen. The ranges of the two species and the status of the names *melaleucalis* Walker (type locality Ceylon) and *reconditalis* Walker and *leucophaealis* Walker (type localities both in Australia), cannot be defined until further tropical material has been studied. *D. ramburialis* should be struck from the North American list, pending the discovery of authentic material, and *D. leodocusalis* Walker entered in its place. It will be noted that *D. leodocusalis* is not known north of Florida, whereas *D. ramburialis* ranges well into the temperate zone.

Diasemiodes, new genus

Type species: *Diasemiodes janassialis*, new combination=*Desmia? janassialis* Walker (Fig. 15)

Frons flat and oblique; labial palpus porrect, third joint concealed in vestiture of second; maxillary palpus with third joint ending in a broad tuft of scales; antenna annulated with scales. Fore wing with R_1 arising near end of cell; R_2

Figs. 10-15. Genitalia. 10, *Choristostigma plumbosignalis* (Fernald), ♂. 11, *Diasemiopsis ramburialis* (Duponchel), ♂. 12, the same, ♀. 13, *Diasemiopsis leodocusalis* (Walker), ♂. 14, the same, ♀. 15, *Diasemiodes janassialis* (Walker), ♂.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free; R_3 and R_4 stalked less than half-way from cell to margin; R_5 not approximated to R_{3+4}; M_1 from well below angle of cell; mdc incurved; M_2, M_3 and Cu_1 distinctly separated at origin; 3rd A prominent. Hind wing with Sc and R_s anastomosed for a considerable distance; mdc uniformly curved so that cell tapers to a point, M_2 and M_3 stalked for a short distance; Cu_1 from angle of cell. Male genitalia with uncus rather short and broad, expanded at tip and covered dorsally with anteriorly directed spines; valve not very wide; costa tubular and strongly curved; a small membranous process in place of clasper; penis relatively large; no prominent cornuti, but a number of minute spicules in the vesica.

I have not structurally examined authentic material of *Pyrausta nigralis* Fernald, but I think this species is more probably related to *janassialis* than to *litterata*; it can accordingly be known for the time being as *Diasemiodes nigralis* (Fernald), new combination.

The following key will separate the six genera discussed here:

1. Third joint of labial palpus porrect, exposed, lying along the scales of the oblique second joint; tip of uncus dilated and spined, valve unarmed, penis with cornuti ..... *Diasemiopsis*
   Third joint of labial palpus concealed in the vestiture of the porrect second joint; if tip of uncus dilated and spined, valve armed with at least a small process on inner surface 2
2. Antenna filiform; tip of uncus dilated and spined, valve armed inwardly with a T-shaped process ..... *Udea*
   Antenna annulated with scales; inner process of valve not T-shaped 3
3. Margin of hind wing evenly curved 5
   Margin of hind wing obviously sinuate 4
4. Uncus absent; valve unarmed ..... *Diasemia*
   Uncus present, its tip dilated and spined; valve with a setose process on inner surface ..... *Diasemiodes*
5. Uncus absent; transtilla and costa of valve with setose processes ..... *Choristostigma*
   Uncus tapering, spined at tip; transtilla and costa of valve without setose processes ..... *Daulia*

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Studies on the Arborvitae Leaf Miners in New Brunswick (Lepidoptera: Yponomeutidae and Gelechiidae)[1]

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Introduction

In 1947 and 1948 brown foliage on arborvitae trees caused by leaf miners became increasingly noticeable in New Brunswick. Since the literature contained little information on the miners this study was undertaken in 1950 to obtain information on their biology, control, and effect on the host tree. Part of the study dealing with the separation of the four species of leaf miners, *Argyresthia thuiella* (Pack.), *A. freyella* Wlshm., *A. aureoargentella* Brower, and *Recurvaria thujaella* Kft., is being published as a separate paper (7). This paper is concerned with the life-history and associated studies.

Distribution

The exact range of the arborvitae leaf miners is difficult to determine owing to uncertainty about the species involved. Most papers refer to *A. thuiella* or simply the arborvitae leaf miners; it is probable that usually more than one species was present. *A. thuiella* has been recorded from Ontario and Quebec south to Pennsylvania and as far west as Missouri. *A. freyella* has been reported from Quebec and Ontario south to New York, *A. aureoargentella* from Maine and New Brunswick, and *R. thujaella* from Maine and New Jersey (3). Closer search might reveal a much wider distribution.

In New Brunswick all four species are most numerous in the southwestern counties of York, Sunbury, and Charlotte. Samples and reports were received from the northern and eastern counties but the populations were lighter and more scattered.

Hosts

The common host of the four species is the arborvitae or eastern white cedar, *Thuja occidentalis* L. *A. freyella* has been found on red cedar, *Juniperus virginiana* L. by several workers (2, 3, 5), and *A. thuiella* was recorded from Utah juniper, *Juniperus utahensis* Engel. (3).

Life History and Habits

Field observations at Fredericton were made periodically, and other areas visited whenever possible. Infested foliage was examined periodically throughout the study. Preserved insect material collected in the first years was later identified to species when possible. This gave specific information on the biology of the leaf miners, but as *A. thuiella* was the predominant species at Fredericton the information obtained was, for the most part, indicative of this species. Individual vial and cage rearings were conducted throughout the study.

During the study it was found necessary to develop a terminology to apply to the arborvitae foliage. Fig. 1 shows a typical spray of arborvitae. The apical growth was termed the lateral, and the side shoots were called side-laterals. The leaves take the form of leaf scales, and are in a three-in-a-row arrangement, as designated numerically on the illustration.

Adult Stage

Emergence dates are shown in Table 1. The first date of emergence was taken as the day when the first empty pupal case was found in the field or the

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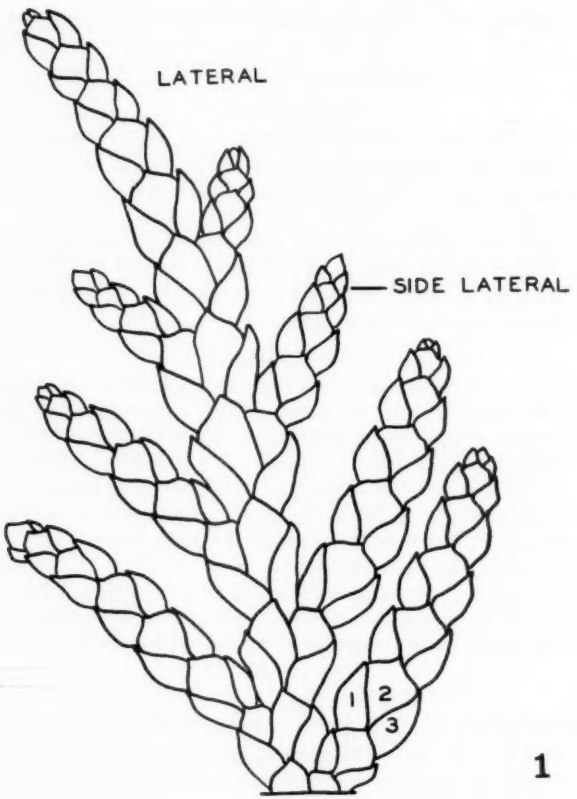

Fig. 1. Typical spray of arborvitae foliage showing the lateral, side-laterals, and the three-in-a-row arrangement (Nos. 1, 2, and 3) of the individual leaf scales.

first adult seen or collected, and the last date as the day when no more sound pupae were found. The peak emergence was about July 1 for the *Argyresthia* species, and up to two weeks later for *R. thujaella.*

The pupae of *A. thuiella* are usually near the tip of the mine. After the adult emerges from the pupa it moves along the mine to the apex of the mined leaflet, which is usually broken off, and escapes. Adults of *R. thujaella* emerge in much the same way as described above. The cocoon spinning species have no difficulty in emerging, making their exit from the end of the cocoons.

A. thuiella adults are weak flyers. Adults observed in the field restricted themselves to short flights from one portion of the tree to another, or to another nearby tree. When at rest the prothoracic legs are raised.

Nine caged females of *A. thuiella* laid an average of 10.2 eggs (range 1 to 25) and contained an average of 11.7 mature eggs in the ovaries after egg laying for a total potential of 21.9.

TABLE 1
Emergence dates of adults of arborvitae leaf miners for the years 1950 to 1953. Data collected at Fredericton and vicinity

Year	Species	Emergence dates		
		First	Last	Median
1950	*A. thuiella*	June 10	July 14	June 27
	*A. freyella**	June 20	July 11	July 1
	R. thujaella	July 14	July 18	July 16
1951	*A. thuiella*	June 21	July 9	June 30
	*A. freyella**	June 24	July 11	July 2
	R. thujaella	July 5	July 17	July 11
1952	*A. thuiella*	June 17	July 23	July 5
	A. aureoargentella	June 16	July 10	June 28
	A. freyella	June 19	–	–
	R. thujaella	June 28	July 5	July 2
1953	*A. thuiella*	June 12	July 15	July 2
	A. aureoargentella	April 27	July 10	June 28
	A. freyella	April 25	July 10	–
	R. thujaella	June 24	July 16	July 1

*Includes *A. freyella* and *A. aureoargentella*.

Egg Stage

No actual mating or oviposition was observed. Some eggs were obtained from reared stock. Eggs were laid from two to seven days after emergence. In 1950 the first egg in the field was found July 5, about a week after the peak emergence, and the last on August 5.

The eggs are wedged between the base of one leaf scale and the upper edge of the adjoining leaf scale or, less commonly, in the axil between two leaflets. All eggs are laid on the current season's foliage. *A. thuiella* eggs from caged adults were located an average of five leaf scales from the apex of the leaflet with a range of two to nine. Eggs in the field averaged four leaf scales from the apex, with a range of one to 10. The mode in both cases was four.

In 1950 the first empty egg was found on July 21, 16 days after the first sound ones were observed. The last sound egg was found August 5. Reared eggs of *A. thuiella* hatched in from 11 to 20 days with an average of 17 days.

Larval Stage

Few first-instar larvae of *A. thuiella* were observed on the foliage as they start mining the same day they hatch. They usually enter the underside of the foliage from the tip to nine leaf scales back from the apex. Some larvae enter between two scales, but most entrance holes are chewed straight through the epidermis, either along the edge or in the centre. The young larvae mine through the first scale and then start excavating the second. The mine extends away from the tip, but some larvae that enter back from the apex mine the tender growing end of the leaflet before returning to the normal pattern. All three scales in a row are usually mined, but some larvae will feed down one side of the leaflet for a short distance and then revert to mining all three leaf scales in a row.

Up to three instars may be found in the field through August and September (Table 2). The average number of leaf scales mined increased with each succeeding instar but the range was so great that this could not be used as a criterion

TABLE 2
Dates on which larval instars of *A. thuiella* were observed in the field at Fredericton. 1950–1953

Instar	Observed in the field	
	From	To
I	July 20	August 19
II	August 2	August 30
III	August 14	September 8
IV	August 22	overwinter
V	September 22	overwinter
VI	spring feeding	June 5

for instar determination (Table 3). Probably some larvae were ready to moult while others had just moulted when measurements were taken. This could account for some of the overlap in range. Stage V is an example. Collections made while feeding was in progress averaged 15.2 mined leaf scales per larva. The same instar had an average of 26.0 mined leaf scales after feeding was completed in the fall, and there was also a comparable increase in the upper limits of the range. The instars of spring larvae were grouped as so few larvae survived.

In 1950 feeding continued into November. By November 10 some larvae were in hibernation and all instars were inactive by December 1. The majority of the overwintering larvae were Stage V, although one Stage VI, some Stage IV, and several Stage III were found. The winter is passed in the mine next to or only one or two leaf scales from the green foliage. A silk chamber or web is spun before hibernation.

Hibernation is easily broken. A collection made in February at below zero temperature was examined as soon as it was taken into the laboratory. Within

TABLE 3
Accumulated number of leaf-scales mined by different instar larvae of *A. thuiella*. Fredericton. 1950–1953

Instar	Number of observations	Average number of leaf scales mined	Range
I	50	2.1	1– 5
II	43	5.1	1–16
III	28	8.4	5–18
IV	22	12.0	6–18
V	46	15.2	7–25
V (Overwintering)	20	26.0	11–36
V and VI Spring feeding	12	44.0	22–72

an hour many larvae were active, and feeding commenced within a day. Some larvae pupated less than a month after collection.

In 1950, feeding was first observed on May 8, about the time the cedar buds were bursting. In 1953, larvae were active on one protected tree at the end of March and considerable feeding was observed by the middle of April.

The amount of spring feeding prior to pupation varied greatly. The maximum number of leaf scales excavated in one day was five. Feeding is completed two to four days before pupation. The larva then migrates to the old end of the mine, turns around facing the exit, and remains inactive until pupation occurs. The mines, particularly in the later instars, are kept relatively free from frass. This is accomplished by means of frass ejection holes which are cut through the epidermis of the leaves. When the mine is long, a second frass exit is cut and the first one is covered over. If the first one is torn open mechanically the larva immediately repairs the break. A maximum of three such holes was found per mine.

Several insectary reared larvae left the original mine. One attempted to start a new mine, but later returned to the original mine. Two other larvae remained on the surface of the foliage and pupated at the bottom of the rearing vials.

The last full-grown larva was found in the field on July 5.

The small number of *A. freyella* and *A. aureoargentella* available prevented a complete study of their larval stages. Sufficient information was collected to show their phenological development is similar to *A. thuiella* but their habits differ in several respects from *A. thuiella*. Both tend to mine down one side of the leaflet rather than hollow all three scales in a row. The frass is not cleared from the mines. They also differ from *A. thuiella* in that the larval stage is spent in several mines rather than one. The length of these mines varies from as few as five leaf scales to as many as 40.

The seasonal history of *R. thujaella* differs from that of *Argyresthia* in that the winter is usually passed in either the second or third larval instar. The amount of fall feeding is much less than for the other leaf miners; sometimes only five to ten leaf scales are excavated. The mines are almost always in the tips of the new shoots. The winter is passed in a silk-lined chamber. Spring feeding is resumed about two to three weeks later than the other leaf miners, which accounts for the somewhat later adult emergence. With few exceptions all three leaf scales in a row are mined. Some individuals tend to mine down the axis of the foliage sprays to reach another leaflet. Most of the larvae complete their development in one mine, but some will start new ones. The spring mines are usually cleared of frass by means of frass ejection holes. Approximately eight leaf scales are mined per larva in the fall and from 20 to 58 in the spring. Feeding ceases about two days before pupation. The larva moves to the end of the mine near the exit, may or may not line the chamber with silk, and then pupates.

Pupal Stage

Pupae of *A. thuiella* and *R. thujaella* are always in the mine. The other two species pupate in cocoons spun on the surface of the foliage. The cocoons are usually found singly but in 1951 nine pairs of *A. aureoargentella* cocoons were found side by side. No *A. freyella* cocoons were found in pairs. A count made in 1950 showed 94 per cent of the cocoons of both species on the lower side of the foliage.

The length of time spent in the pupal stage for each species is as follows:

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Species	Average number of days	Range in days
A. thuiella	19	16–25
A. freyella	18	15–20
A. aureoargentella	18	16–30
R. thujaella	18	14–21

Estimate of Damage

The effect of individual larvae on the host was determined by field and laboratory observations. Whenever it was possible the total number of scales mined was recorded, as well as the number of leaf scales killed as a result of feeding. The effect of the arborvitae leaf miner complex on stands of trees was determined by annual inspection of five sample plots laid out in 1950. The trees were tagged and tallied by D.B.H., crown class, defoliation, and browning. The classification for both browning and defoliation as used in 1950 and 1951 was as follows:

Index	Condition	Percentage of defoliation and browning
1	normal	0
2	light	1– 33
3	medium	34– 66
4	heavy	67–100

After the first two years classes 1 and 2 were found to be too broad for critical analysis. Therefore, the following revision was introduced:

Index	Condition	Percentage of defoliation and browning
0	normal	0
1	trace	1– 10
2	light	11– 33
3	medium	34– 66
4	heavy	67–100

Feeding by Individual Larvae

Individual larvae cause damage to the tree in three ways: (1) killing leaf scales directly by mining; (2) killing leaf scales indirectly as a result of feeding and; (3) stopping growth in attacked leaflets.

The amount of feeding by *A. thuiella* larvae has already been discussed (Table 3). In addition to this, the amount of foliage killed indirectly, while great, averages less than the total amount of mining.

TABLE 4

Feeding damage inflicted on the host tree by 15 larvae of *A. freyella* and/or *A. aureoargentella*. Fredericton. 1953

Number leaf scales mined	Number leaf scales killed indirectly	Total kill	Percentage killed indirectly
15	56	71	79
14	28	42	67
16	37	53	70
9	51	60	85
18	58	76	76
12	25	37	67
14	117	131	90
15	45	60	75
11	27	38	70
22	51	73	70
17	206	223	92
16	220	236	93
11	330	341	97
9	19	28	68
6	48	54	89
Total 205	1,318	1,523	—
Average 13.7	87.8	101.5	86

As a rule *R. thujaella* kills indirectly considerably less foliage than is mined. A small number of observations showed an average of 45 leaf scales mined and 32 killed indirectly. As mentioned before, this species tends to enter the foliage near the apex of the shoots, thus killing less foliage as a result of feeding. However, the number of records was small.

Theoretically, *A. freyella* and *A. aureoargentella* are capable of inflicting more damage than the other two species. As the numbers available for study were small, the effect a large population would have on a tree is unknown but some indication can be obtained from Table 4. As each larva of these two species habitually leaves one mine to make another during its development, each individual is capable of causing considerable damage. The amount of foliage killed is greatly in excess of the feeding damage as the larvae often make a short mine which kills several side lateral and lateral shoots.

The growth of infested leaflets is not seriously affected until after the last week of August. However, as the lateral branches have completed over 85 per cent of their annual growth by this time the actual loss in increment is very small. The real damage shows up the next spring in the dead, non-productive foliage tips.

Effect of the Leaf-Miner Complex on Stands

Leaflets attacked by leaf miners one year turn brown and drop the following year. When classifying trees, the normal browning, which is high in the spring,

TABLE 5

Index of feeding by arborvitae leaf miners on eastern white cedar trees in permanent sample plots. New Brunswick. 1950–1953

Plot locality	No. trees	Av. defoliation				Av. browning				Mortality no. of trees
		1950	1951	1952	1953	1950	1951	1952	1953	
1 McAdam	32	1.6	2.3	1.3	0	2.2	2.8	1.6	1.0	1
2 McAdam	24	2.0	2.6	1.7	0	2.1	2.8	1.4	1.0	–
3 McAdam	100	2.2	2.0	1.4	0	2.1	2.1	1.1	1.0	4
4 Fredericton	80	1.1	–	1.4	0	1.9	–	1.0	1.0	4
5 Acadia Sta.	60	1.1	–	1.4	0	2.0	–	1.0	1.0	3
Total	296									12

must be considered. Defoliation is classed as foliage lost on the green section of the branches. By keeping these points in mind it is possible to estimate the defoliation and the browning attributable to insects. The current infestation had started in 1947 or 1948 and reached its peak in 1950. By 1952 the condition of the trees had improved so much that the revised classification was adopted to give a better picture of the lowered insect damage. The average condition of the five plots from 1950 to 1953 is shown in Table 5.

The heaviest attack occurred in the vicinity of McAdam. Five trees were killed in Plots 1 and 3 by 1953, at least two as a result of leaf miner attack. On these two trees the browning and defoliation reached index 3 or 4 before the trees succumbed. The dead trees in plots 4 and 5 were less heavily attacked. It is uncertain whether the leaf miners were the direct cause of death or a contributing factor. Some trees in the plots were over two-thirds defoliated with a similar degree of browning on the remaining foliage, but they are still alive and apparently recovering by putting out fresh foliage on the stem and branches.

Cedar trees in the vicinity of plots 1, 2, and 3 suffered up to 50 per cent defoliation with up to 60 per cent of the remaining foliage browned. Some mortality occurred in 1952, but by 1953 the stands appeared comparatively healthy.

From these studies it is apparent that the leaf miners are capable of killing forest trees. Nevertheless, in the heaviest infestation in New Brunswick relatively few were killed. Trees may lose up to 80 per cent of their foliage and survive a leaf miner attack.

Control

This study provided information on a number of control factors, mainly chemical spraying and parasites.

Chemical Control

An experiment was conducted in 1950 on the effects of various chemical sprays. The results show that lead arsenate or DDT at five pounds per 100 gallons of water with one pint of linseed oil gave the best control (8). There was no indication that two applications of spray increased the control. Brower recommended nicotine sulphate, one quart to 100 gallons of water with 1½ pounds of laundry soap or other spreader (4). Britton and Zappe's experiments were inconclusive in respect to individual chemicals (1).

Natural Control

Natural control studies consisted mainly of rearing, identifying, and assessing the role parasites played in control. The heavy mortality encountered in rearing prevented a critical assessment of other factors. No disease was found, and no predation was observed at any time.

Parasitism was the largest single factor in the control of the leaf miners. Few early-instar larvae were killed by parasites but high parasitism was encountered in mature larvae and pupae. At the height of the infestation in 1950 and 1951 total parasitism accounted for over 60 per cent of the larval population of the *Argyresthia* spp. In 1953, the first year in which figures were available, only 2 per cent of the *Recurvaria* larvae were killed by parasites; in 1954 this increased to 22 per cent.

The 27 species of parasites recovered in New Brunswick, all belonging to the order Hymenoptera, are shown in Table 6. The following species were recorded by the Forest Insect Survey in Ontario.[1]

Argyresthia thuiella Pack.	*Argyresthia freyella* Wlshm.
Pentacnemus bucculatricis How.	*Orgilus obscurator* Nees.
Ascogaster sp.	*Compoplex* sp. near *argyresthiae* (Roh.)
Apanteles sp. near *californicus* Mues.	*Ascogaster* sp.
	Apanteles sp. near *californicus* Mues.
	Apanteles sp. near *paralechiae* Mues.
	Pentacnemus buccalatricis How.
	Spilochalcis sp.

Many of the parasites from Ontario were recovered during or before 1951. At that time *A. freyella* included the new species *A. aureoargentella*, so it is not known if all the parasites listed are actually associated with the species indicated.

P. bucculatricis appears to be more widely distributed than the other parasites. In addition to New Brunswick and Ontario it was also reared in New York and Connecticut (1). Other parasites not found in Canada to date are *Apanteles bedelliae* Vier. from *A. thuiella* (1), and *Microgaster zonaria* Say, formerly *Protopanteles recurvariae* Ashm., from *R. thujaella* (6).

Larval Sampling

Sampling was conducted in the Spring of 1950 at Fredericton, New Brunswick. Population studies were difficult to conduct because of the larval mining habits. Frass drop could not be used because all or a portion is retained in the mines. Cocoon counts would include only two species. It was finally decided to count the over-wintering larvae for the following reasons; (1) the winter season made it easier to obtain the extra help required, (2) the mines are large enough to be seen easily, and (3) the development of the larvae is arrested, thus making all counts comparable as to stage sampled.

The sample trees were classified by degree of browning and defoliation as previously explained and then cut. The crown was divided into four equal length vertical sections. Four sample branches were selected from the centre

[1]Personal communication: Dr. B. M. McGugan, Ottawa, Ontario. February 8, 1955.

TABLE 6

Parasites reared from arborvitae leaf miners in New Brunswick

Parasite species	Host, stage killed, and remarks
Ichneumonoidea	
Braconidae	
Orgilus sp.	*R. thujaella*, larva
Agathis n. sp. near *laticinctus* (Cress.)	*R. thujaella*, stage uncertain
Apanteles ornigis Weed	*A. aureoargentella*, cocoon
Apanteles n. sp. near *betheli* Vier.	*A. aureoargentella*, cocoon
Apanteles n. sp. 46	*A. aureoargentella*, cocoon
Apanteles n. sp. 130	*A. aureoargentella*, cocoon
Ichneumonidae	
Alegina sp.	*R. thujaella*, pupa. This species is believed to be a hyperparasite.
Gelis tenellus (Say)	*A. aureoargentella*, cocoon
Gelis sp. 1	*A. aureoargentella*, cocoon
Gelis sp. 2	*A. freyella* and *A. aureoargentella*, cocoon. This species is believed to be a hyperparasite. Two of this species, both from *A. freyella*, were associated with *Campoplex* cocoons; all the others were associated with *Apanteles* cocoons.
Gelis sp.	*A. thuiella*, stage unknown
Campoplex sp. near *argyresthiae* (Roh.)	*A. freyella* and *A. aureoargentella*, cocoon
Chalcidoidea	
Eulophidae	
Pnigalio maculipes (Cwfd.)	*Argyresthia* sp., larva
Pnigalio sp. near *coloni* (Gir.)	*A. thuiella*, stage uncertain
Pnigalio sp. likely *tischeriae* (Ashm.)	*A. thuiella*, larva
Pnigalio sp.	*A. thuiella*, larva
Sympiesis sp.	*Argyresthia* sp.
Dicladocerus sp. not *westwoodi* Westwood	*A. thuiella*, larvae
Dicladocerus n. sp.	*A. thuiella*, larva
Tetrastichus sp.	*A. freyella*, pupa
Cirrospilus cinctithorax (Gir.)	*A. freyella*, pupa
Zagrammosoma nigrolineatum Cwfd.	*Argyresthia* sp., larva
Derostenus fullawayi Cwfd.	*A. thuiella* and *Argyresthia* sp., larva and pupa. Male and female adults were recovered from the same host, up to five specimens from an individual carcass.
Encyrtidae	
Pentacnemus bucculatricis How.	*A. freyella* and *A. aureoargentella*, cocoon. Parasites emerge from prepupal larva in the cocoon. From one to three emergence holes are found in the cocoon. An average of 3.3 males and 4.0 females were obtained, only one sex from the individual cocoons.
Copidosoma nanellae Amer. authors, not Silvestri	*A. aureoargentella*, cocoon. Only two records, four males from one, four females from the second host.
Eupelmidae	
Eupelmella vesicularis (Râtz.)	*A. thuiella* and *Argyresthia* sp., larva and pupa. One of the parasites is recorded as a hyperparasite.
Chalcididae	
Spilochalcis albifrons (Walsh)	*A. aureoargentella*, cocoon; *A. thuiella*, pupa

TABLE 7
Analysis of variance showing difference between trees, crown levels, and direction. Data collected at Fredericton, N.B., 1950

Source of variation	D. F.	S. S.	M. S.	F.
Trees	3	2,102.59	700.86	1.77
Levels	3	1,198.75	399.58	1.01
T x L	9	3,555.12	395.01	3.13*
Direction	3	308.03	69.34	<1
T x D	9	1,519.64	168.85	1.34
D x L	9	470.51	52.28	
D x T x L	27	3,404.01	126.07	
Total	63	12,458.65		

*Significant at the 5 per cent level.

of each section, one from each of the four cardinal compass points. The area of each branch was measured and the branch divided into two bi-lateral sections and examined for larvae.

After the first two trees were sampled, the branch halves were compared. The t value of 1.0 indicated that there was no significant difference between branch halves so future sampling was conducted by examining only one-half of each branch. The number of larval counts on subsequent sampling was doubled to obtain comparable figures. This refinement resulted in a time saving of about 45 per cent.

To determine if any further refinement of the sampling procedure was possible the data were analyzed on a square foot basis. The analysis of variance is shown in Table 7. The differences between direction, trees, or crown levels were not significant, but on the basis of variance, there was more difference between trees and levels. It was therefore concluded that in future work one branch would be selected from each of the four crown levels, thereby increasing the number of trees which could be sampled with the same expenditure of time.

Summary

Studies on the arborvitae leaf miners, *Argyresthia thuiella* (Pack.), *A. freyella* Wlshm., *A. aureoargentella* Brower, and *Recurvaria thujaella* Kft., were conducted in New Brunswick from 1950 to 1953. The principal host tree of all species is the eastern white cedar, *Thuja occidentalis* L. The leaf miners are found generally throughout the range of the host tree.

The life history of *A. thuiella* is as follows. The adults emerge from the middle of June to the middle of July and lay up to 25 eggs each on the new foliage. The eggs hatch in from 11 to 20 days and the larvae start mining immediately. The winter is passed as a fifth-instar larva. Feeding resumes in early May and the larvae pupate in the mines in late May and June. The entire larval life is spent in one mine. The pupal period lasts from 16 to 25 days. The life histories of *A. freyella* and *A. aureoargentella* are similar in respect to dates but the habits differ. The larvae make two or more mines during their development, and pupate inside a cocoon spun on the foliage surface. *R. thujaella* adults

emerge up to two weeks later than *A. thuiella* and the larvae overwinter in the second or third instar. Pupation occurs in the mine. The entire larval life is usually spent in one mine.

A. thuiella and *R. thujaella* kill less foliage as a result of mining than they do by feeding. The proportion of indirect kill is much greater for the two cocoon-spinning species. Heavy populations of all species combined caused up to 80 per cent defoliation of plot trees, but relatively few trees died.

Larval populations were estimated by counting the number of mines per square foot of foliage surface. Four sample branches, one from each of the four crown levels, is sufficient to give a good estimate.

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Spray Chamber Insecticide Tests on the Larch Sawfly (*Pristiphora erichsonii* (Htg.))

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Experimental aerial spraying by Butcher (3), Butcher and Eaton (4) and Peterson (7) has been described; but potency tests of the synthetic organic insecticides against the larch sawfly, *Pristiphora erichsonii* (Htg.), have not been reported.

The first screening tests were carried out in 1955 at Cass Lake, Minn., with DDT, chlordane, methoxychlor, benzene hexachloride (BHC) and malathion against larvae of each of the five different instars[3]. High temperatures in the field laboratory killed an inordinately large proportion of the control insects, making interpretation of the test data hazardous. Examination of the data indicated that BHC and malathion were the only promising toxicants. Work was continued by the author at Cass Lake in 1956 with these insecticides as well as with DDT, which has been used frequently against forest defoliators.

Procedure

The test insecticides were DDT[4], BHC[5], and malathion[6] at concentrations of 0.1, 0.025, 0.0125, 0.00625 and 0.003125 pound per gallon (U.S.).

Each concentration of each insecticide was individually prepared as follows: The insecticide was dissolved in 1 quart of xylene, and enough No. 2 diesel oil was added to make a gallon of solution. Nine grams of DuPont oil red dye were added to each gallon for dye-tracer determination of the applied insecticide. A sample from each gallon of insecticide was diluted to the equivalent of 1 gallon per acre (gpa) over ¼ square foot (standard solution). These were tested with a Spencer colorimeter to an accuracy of 1 gpa $\pm$ 0.05. The standard solutions were used as a check against each application on a ¼ square-foot aluminum plate to 1 gpa $\pm$ 0.1, before and after the larvae were sprayed.

The test chamber was similar in construction to one developed by Eaton and Secrest (5) (Fig. 1). It was built at the University of Minnesota Scientific Apparatus Repair Shop, where the original shutter and timing mechanism were improved. The insecticide was propelled by compressed carbon dioxide and delivered at 5 pounds per square inch, yielding drops of about 80 microns mass median diameter.

Larvae were field collected just prior to the testing. Each insecticide and concentration was applied to 5 replications of 10 larvae each. The 10 larvae were placed on clean paper, sprayed, and transferred to freshly cut tamarack foliage in a vial of water. Three 5-inch stems per vial sufficed for a 24-hour feeding of 10 fourth- and fifth-instar larvae. The larvae and vial of foliage were held in a cage consisting of a paper quart ice cream container with both ends removed and replaced with cloth netting (Fig. 2). The cages were examined daily to record the living, dead and moribund[7], and missing larvae and to replace the foliage. At the end of 3 days final counts were made.

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2Maintained at St. Paul 1, Minn., in cooperation with the University of Minnesota.
3Information obtained from Mr. J. P. Secrest, Entomologist, U.S. Department of Agriculture, Forest Service, Beltsville, Maryland.
4 100 percent active.
5 43½ percent gamma.
6 95 percent active.
7Moribund—shrunken larvae still sensitive to touch, but incapable of locomotion.

Fig. 1. Spray chamber used for insecticide studies on the larch sawfly. Compressed carbon dioxide propelled the solutions through an atomizer into the chamber when the timer (to the right of the operator's hand) opened the shutter. Waste spray was collected in a gutter below the atomizer nozzle and piped into the glass jug below the timing device.

Two series had to be rerun due to rodent predation. The data for the untouched cages were recorded, and the percent killed was similar for the additional tests. In the calculation of dosage-mortality these data were combined.

Two series of control were maintained: (1) unsprayed and (2) dyed solution minus insecticide. The results from the latter control were used to correct the mortalities in the insecticide tests. Fortunately cool weather prevailed in 1956, and favorable laboratory temperatures (18.5°C±2.5) minimized losses.

The LD_{50} (lethal dosage when 50 percent effective) and LD_{90} of the active ingredient were computed according to Bliss (2) and Finney (6). The net mortality was computed using Abbott's method (1).

Results

Early in the experiment it became apparent that 0.1 lb. per gpa of DDT (100 percent), BHC (43.5 percent gamma), or malathion (95 percent active) would kill first- and second-instar larvae on contact (Table I). At a concentration of 0.0125 lb., DDT failed to give desired results, whereas the BHC and

Fig. 2. Sprigs of foliage were kept fresh in vials of water. The insects were placed upon the foliage and caged in a paper quart ice cream container. The ends of the container were replaced with cloth netting.

TABLE I

Mortality data for larch sawfly larvae treated with DDT, benzene hexachloride (BHC), and malathion; Cass Lake, Minnesota, 1956

No. of larvae tested with—					Dosage (lb./gal./A)	Date	Percent mortality with—[1]							
							DDT		BHC		Malathion		Un-sprayed	Dye+oil
DDT	BHC	Mal.	Un-sprayed	Dye+oil			Test	Cor-rected	Test	Cor-rected	Test	Cor-rected	Test	Test
						First- and second-instar larvae								
49	47	50	45	49	0.1	June 29	100.0	100.0	100.0	100.0	100.0	100.0	8.9	14.3
50	49	50	50	49	0.0125	July 3	22.0	15.0	100.0	100.0	96.0	95.6	4.2	8.2
						Fourth- and early fifth-instar larvae								
50	40	50	50	50	0.025	July 10	12.0	0.0	92.5	91.5	100.0	100.0	10.0	12.0
49	39	50	50	29	0.0125	July 9	8.9	5.6	74.5	73.6	82.0	81.3	4.0	3.5
–	20	49	30	45	0.00625	July 11	–	–	70.0	68.6	53.1	50.9	13.4	4.4
–	50	49	50	50	0.00625	July 20	–	–	70.0	68.8	59.2	57.5	8.0	4.0
–	70	98	80	95	0.00625	July 11+20	–	–	70.0	68.7	56.1	54.2	10.7	4.2
–	(2)	40	(2)	40	0.003125	July 13	–	–	(2)	–	37.5	35.9	(2)	2.5
–	50	49	50	50	0.003125	July 20	–	–	56.0	54.2	38.7	36.1	8.0	4.0
–	50	89	50	90	0.003125	July 13+20	–	–	56.0	54.5	38.1	36.0	8.0	3.3
						Late fifth-instar larvae[3]								
–	49	–	49	49	0.00625	July 1	–	–	12.2	10.4	–	–	6.1	2.0
–	49	50	49	49	0.003125	July 16	–	–	12.2	10.4	6.1	4.2	6.1	2.0

1 Corrected percents are computed with Abbott's formula: $P^1 = \frac{P-C}{1-C}$ where P^1 = corrected mortality percent, P = tested mortality percent, and C = control (dye+oil) mortality percent.

2 Destroyed by rodents.

3 17.5% of the larvae cocooned during the 3-day test period.

malathion remained potent. In the series of tests against fourth- and early fifth-instar larvae, DDT was tested (along with BHC and malathion) at 0.025 and 0.0125 lb. per gpa, and it became clear that DDT would not be effective as a contact insecticide at these concentrations against the larch sawfly. Therefore it was eliminated from further experimentation. Comparison of the LD_{50} and LD_{90} of BHC with malathion indicates that BHC is more effective at lower concentrations (Table 2). This tendency diminishes until about LD_{98} where the toxicants are theoretically equivalent (0.0468 lb./gpa).

In comparison with the earlier instar larvae, those in the latter part of the fifth instar were quite resistant to the concentrations of BHC and malathion tested against them (Table 1). Time limitation precluded additional tests at higher dosages against the late fifth-instar larvae.

Discussion

Spray chamber contact insecticide tests serve to eliminate unsatisfactory toxicants. The problem of successful aerial application lies ahead. Anyone familiar with the life history of the larch sawfly could enumerate the obstacles to good insecticidal control among which are: prolonged adult emergence resulting in overlapping larval instars and the periodic presence of all stages simultaneously; occasional prepupal diapause beyond one season; parthenogenetic reproduction producing nearly all females; and differing adult emergence patterns from site to site. Seasonal differences should also be considered, since warm April-May weather is indicative of early and more rapid larch sawfly activity than when the weather is cold through that period The chances for good control in north central Minnesota would be better theoretically during years when April and May temperatures are above normal. This would shorten the period between early larval drop and late oviposition, reducing the necessity of spraying before almost all of the hatching has occurred.

If only a single application of insecticide is planned, timing may not be too critical, keeping in mind that some larvae have cocooned when late emerging adults will still be ovipositing. The data show that the larvae as they grow older display an increasing resistance to insecticides (Table 1). It is suggested therefore that insecticides be applied 10 days to 2 weeks after the first fifth-instar larvae have been observed. An additional spray operation 2 weeks later should result in very good control for the season, and it may suffice for the second year.

Summary

Spray chamber contact insecticide tests were carried out against the larch sawfly at Cass Lake, Minn., during June and July 1956.

Different concentrations of DDT, benzene hexachloride (BHC), and malathion were applied to series of larvae of first and second, fourth and early fifth, and late fifth instars. At the concentrations and dosages used, DDT failed, but BHC and malathion gave satisfactory results against larvae of first and second, and fourth and early fifth instars. Comparison of the LD_{50} and LD_{90} for the two toxicants against the fourth- and early fifth-instar larvae showed BHC to be more potent than malathion at the LD_{50}, but this advantage decreased as LD_{98} was approached. Additional tests with these insecticides on late fifth-instar larvae were not continued, but it was demonstrated that at similar concentrations used for early fifths, effectiveness was lessened.

Problems that must be considered in planning an experimental aerial control project were discussed. These were focussed upon the life history and biology of the insect.

TABLE II

The LD_{50} and LD_{90} based upon contact with the active ingredients of benzene hexachloride (BHC) and malathion for larch sawfly larvae; Cass Lake, Minnesota, 1956

BHC		Malathion	
Active (lb./gal./acre)	Fiducial Limits[1] (DF = 2)	Active (lb./gal./acre)	Fiducial Limits[1] (DF = 2)
LD_{50} 0.001150.....	± 0.000585	LD_{50} 0.004770.....	± 0.000040
LD_{90} 0.012370.....	± 0.000710	LD_{90} 0.017020.....	± 0.000558

[1] At 5-percent level of significance.

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A Water-Trap for Detecting Insects in Stored Grain[1]

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Much of the losses due to insects in stored grain occur when infestations remain unnoticed because of infrequent or inadequate sampling. There is clearly a need for a simple, sensitive method of indicating the presence of insects in stored grain before they become sufficiently numerous to occur in grain samples.

At the Winnipeg laboratory, jars of water are sometimes used to increase the relative humidity above wheat containing cultures of the rusty grain beetle, *Laemophloeus ferrugineus* Steph. The fact that adults were often trapped in the water suggested a method of detecting insect infestations in stored grain. This paper reports field and laboratory experiments on the general usefulness of a water-trap to detect insects in stored grain.

Methods

The field experiments were carried out during August and September in grain stored in four 1000-bushel granaries and one 25,000-bushel annex. The annex was known to be infested with insects; none were suspected in the granaries.

The water-traps consisted of six-ounce glass jars filled with water to within an inch of the top. Six jars of water were placed in each of the four granaries, and 12 were placed in the annex. They were spaced uniformly and then pushed into the grain so that the tops were level with the grain surface. After a week to ten days the jars were taken to the laboratory and the contents poured through coarse filter paper to remove insects and mites.

Six-ounce samples of grain were taken from the four granaries at six points on the surface and below each point at a depth of three feet. In the annex, 13 six-ounce samples were taken at the grain surface, nine at four feet, and two at eight feet. The samples were sifted at the laboratory to remove insects and mites.

Experiments were conducted in the laboratory on effects of moisture content of grain on the movement of insects towards water. Five basins, 16 inches in diameter and five inches high, were each filled with 12 pounds of wheat with a moisture content of 12 per cent. Six 100-ml. beakers were placed in the wheat six inches from the centre and equidistant from each other. The tops of the beakers were level with the wheat surface. Each alternate beaker was filled with water. A paper baffle was inserted about a quarter of an inch from the top of each empty beaker to prevent insects from crawling out after they had entered.

One hundred of each of the following beetles were introduced just below the wheat surface at the centre of each basin: the granary weevil, *Sitophilus granarius* L.; the rusty grain beetle, *Laemophloeus ferrugineus* Steph.; and the confused flour beetle, *Tribolium confusum* Duv. The beetles were taken from laboratory cultures maintained at 75° to 80°F. and 70 per cent relative humidity. The tops of the basins were covered with plastic sheets to prevent the escape of insects and then with paper to exclude direct light. The covers were partly removed at daily or two-day intervals during 14 days to record the numbers of insects in the beakers. The temperature of the wheat during the experiments ranged from 70° to 74°F.

The experiment was repeated with wheats of 15 and 18 per cent moisture content.

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TABLE I

Percentages of water-traps* placed in four granaries and a storage annex, and also of grain samples**, containing various pests.

Species	Granaries		Annex	
	Traps	Samples	Traps	Samples
Laemophloeus ferrugineus Steph.	0	0	33	5
Cryptophagus spp.	0	0	100	12
Enicmus spp.	25	0	42	0
Psocids	0	44	25	62
Tenebrio molitor L. (larvae)	75	0	0	0
Ptinus villiger (Reit.)	46	0	16	0
Cephalonomia waterstoni Gahan.	0	0	93	12
Cheyletus eruditis Schr.	0	46	16	40
Acarus siro L.	0	46	0	0
Dermestes lardarius L.	20	0	0	0

*Six in each granary, 12 in the annex.
**Six surface samples and six at a depth of three feet from each granary; 13 surface samples, eight at a depth of four feet, and two at eight feet from the annex.

Insect counts in the traps and empty beakers in wheat at 12, 15, and 18 per cent moisture content were tabulated after 8 days. The data were transformed to logarithms to eliminate skewness and make the variance more stable (Snedecor, 1946). Zero values were accommodated by adding unity to all insect counts. Analysis of variance was carried out on the transformed data.

Experiments were carried out also on the effects of depth of infestation in grain on the number of insects in the traps. Galvanized iron cylinders, 14 inches in diameter, were filled with wheat at 12 per cent moisture content to depths of 5, 14, 28, and 60 inches. One hundred adults of each of *S. granarius*, *L. ferrugineus*, and *T. confusum* were placed at the bottom of each cylinder.

Three 100-ml. beakers containing water, and three empty beakers with paper baffles, were placed alternately about six inches apart and equidistant from the centre of the wheat. The beakers were placed so that the lips were level with the wheat surface. The tops of the cylinders were covered to prevent the insects from escaping. The covers were removed at daily or two-day intervals for three weeks to count the insects in the beakers.

Results and Discussion

Most species of insects that commonly infest stored grain in Manitoba were found in the water traps placed in the granaries and the annex (Table 1). In the four granaries, grain sampling yielded only psocids and the mites *Acarus siro* (L.) and *Cheyletus eruditis* Schr. These species were not taken in the traps (which, however, contained adults of *Enicmus* spp. and *Ptinus villiger* (Reit.) and larvae of *Tenebrio molitor* L. and *Dermestes lardarius* L.). In the annex more traps than grain samples contained *L. ferrugineus*; *Cryptophagus* spp.; *Enicmus* spp.; *Ptinus villiger* (Reit.); and *Cephalonomia waterstoni* Gahan., described by Rilett (1949) as a parasite of *L. ferrugineus*. On the other hand, more samples than traps contained psocids and *Cheyletus eruditis* Schr.

Table II shows the effect of wheat moisture content on the numbers of insects taken in the traps and empty beakers. The numbers of *S. granarius* in the traps were significantly greater at the 1 per cent level than those in the empty beakers when the moisture content of the wheat was 12 per cent or 15 per cent; there was no significant difference at 18 per cent moisture content.

TABLE II
Mean numbers (transformed values, log (χ + 1)) of insects obtained from water-traps and empty beakers

Moisture content of wheat, %	*Sitophilus granarius* L.	*Laemophleous ferrugineus* Steph.	*Tribolium confusum* Duv.
Water traps			
12	1.397	1.174	0.115
15	1.225	1.061	0.374
18	0.776	0.585	0.173
Empty beakers			
12	0.363	0.752	1.495
15	0.838	0.666	1.219
18	0.750	0.020	1.155
Difference necessary for significance at 1% level	0.228	0.269	0.692

More of *L. ferrugineus* were taken in the traps than in empty beakers at all moisture contents.

Table II also shows that significantly more of *S. granarius* and *L. ferrugineus* were taken in the traps in wheat of 12 or 15 per cent moisture content than at 18 per cent moisture content. This might be due to increased locomotor activity of insects in dry wheat. Bentley (1944) has reported that desiccated adults of *Ptinus tectus* Boie. were more active than normal ones and collected near the wetter region of a humidity gradient. It might also be due to the wider humidity range between the traps and the drier wheat. A water-trap may be regarded as the wet region of a humidity gradient that decreases concentrically from 100 per cent relative humidity to a lower limit in equilibrium with the moisture content of the grain. Babbitt (1949) has given isotherms that describe the equilibrium relationship between relative humidity and the amount of moisture adsorbed by grain. At 24.5°C., the relative humidities of air in equilibrium with wheats of 12, 15, and 18 per cent moisture are approximately 60, 78, and 86 per cent respectively. These values represent the lower limits of the humidity gradients in the wheat. The insects that became entrapped in the water are those that attempted to collect near the wet region of the humidity gradient.

More of *T. confusum* were found in empty beakers than in water-traps. Roth and Willis (1951) observed similar behaviour in non-desiccated, unstarved adults of *T. confusum* and *T. castaneum*: when the beetles were taken from whole wheat flour, they preferred dry air to moist air when given a choice. After being desiccated and starved for six days the humidity reaction was reversed and the insects came to rest in moist air.

Fig. 1 shows that in wheat at 12 per cent moisture content a large percentage of *S. granarius* and *L. ferrugineus* entered the traps during the first two weeks; few of *T. confusum* were taken in the traps.

Fig. 2 shows that 42 per cent of *S. granarius* and 34 per cent of *L. ferrugineus* placed in grain at a depth of five inches came to the surface and entered the traps. When the grain depth was increased to 14, 28, and 60 inches, fewer insects were taken in the traps. This indicates that the usefulness of a water-trap depends on the depth of an infestation.

Grain temperature is probably the most important single factor affecting the distribution of insects in stored grain. Cotton (1954) has shown that during spring, summer, and autumn the majority of insects are found in the upper half

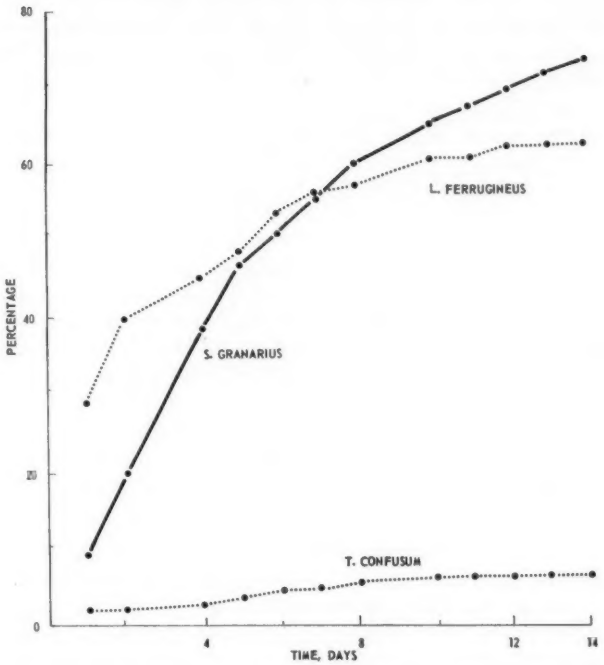

Fig. 1. Percentages of three species of insects taken in water-traps in grain at 12 per cent moisture content.

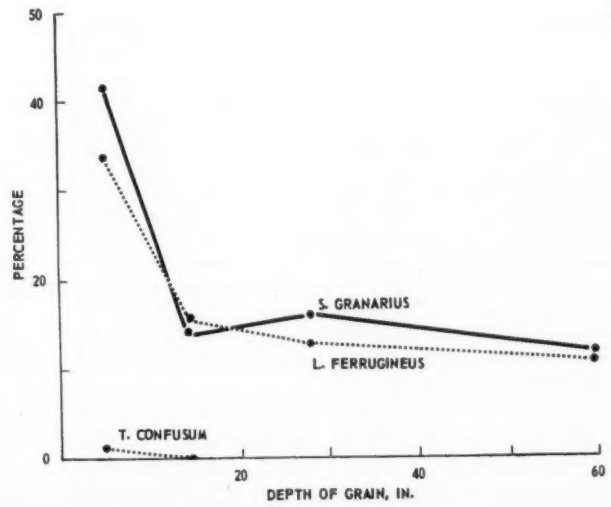

Fig. 2. Percentages of three species of insects taken in water-traps three weeks after being placed at various depths of grain at 12 per cent moisture content.

of grain stored in a bin. In mid-winter insects rarely occur near the surface and seek the warmer regions near the centre. Temperature measurements taken in stored grain in southern Manitoba during winter indicate that the temperature of grain bulks of about 1000 bushels may range from 19.5°F. to 26°F. (Watters, 1955).

The distribution of insects in grain is also affected by moisture content. During winter, grain often becomes damp near the surface. This is due to the movement of water vapour from the warmer to the colder parts of the grain (Anderson *et al.*, 1943). Invariably more insects are found in high-moisture grain than in dry.

The advantages of a water-trap for detecting insects in stored grain are: (1) insects from the surrounding area are concentrated in the trap, (2) no special apparatus is required, (3) it is easy to examine, and (4) the method is generally more reliable than ordinary sampling methods. Disadvantages are: (1) deep-seated, localized infestations may not be detected, (2) fewer insects occur at the surface of grain during cold weather than warm and are less likely to be detected.

Despite its limitations, the method makes it possible to detect infestations in stored grain before they become firmly established. Control measures may then be applied promptly to prevent the serious losses which occur when infestations go unnoticed.

Summary

Field experiments showed that most grain-infesting insects were taken oftener, and psocids and mites less often, in water-traps than in grain samples. In the laboratory, the number of *Sitophilus granarius* L. and *Laemophloeus ferrugineus* Steph. in the traps was inversely related to the moisture content of the grain and the depth of infestation; few of *Tribolium confusum* Duv. were taken in the traps.

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